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THE AUTHORS

John T. Postle, M.Sc., P.Eng., is a Consulting Mining Engineer with Roscoe Postle Associates Inc.

William E. Roscoe, Ph.D., P. Eng., is a Consulting Geologist with Roscoe Postle Associates Inc.

Roy Y. Watanabe, Ph.D., P.Eng., is an independent Consulting Geologist who worked on this review in association with Roscoe Postle Associates Inc.

Philip S. Martin, B.Sc., M.B.A., P.Eng., worked on this review as an independent Mining Financial Consultant in association with Roscoe Postle Associates Inc. Mr. Martin has since become a Partner in a Toronto-based Investment Banking firm.

NOTE:

This background paper does not represent official policy and the views expressed herein are not necessarily the viewpoint of the Government of Ontario.

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REVIEW OF PLATINUM GROUP ELEMENT DEPOSITS IN ONTARIO

BY

JOHN T. POSTLE
WILLIAM E. ROSCOE
ROY Y. WATANABE
PHILIP S. MARTIN

November, 1986

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SUMMARY

This review by Roscoe Postle Associates Inc. (RPA) of the platinum group element (PGE) deposits of Ontario stems from a rapid increase in interest in PGE by the Canadian mining industry in recent years. This interest results from increases in platinum and palladium prices and from increasing uneasiness about long term supply from the Republic of South Africa, who, along with the USSR, are the world's largest producers.

It is important to classify PGE deposits into different types, since most of the world's production comes from just a few types. Common characteristics can be recognized and used for exploration, metallurgical techniques or mining purposes.

PGE deposits worldwide can be classified in the following general framework, with examples:

Group I: Sulphide Association

I.A.: PGE Dominant

Examples: Merensky Reef (Bushveld), Stillwater, Platreef (Bushveld), Lac des Iles

I.B.: Ni-Cu Dominant

Examples: Noril'sk, Sudbury, Kambalda, Duluth, Crystal Lake, Marathon

Group II: Oxide-Silicate Association

Examples: UG2 (Bushveld), Onverwacht

PGE deposits are genetically associated with basic and ultrabasic rocks. Basic rock settings are characterized by platinum group minerals (PGM) which are compounds of S, Sb, As, Bi and Te. The PGE are associated with Ni-Cu sulphides,

commonly as by-products, such as at Noril'sk and Sudbury. In ultrabasic rock settings, PGE deposits are characterized by native PGE alloys, discrete sulphide minerals, and solid solution of PGE in sulphides, olivine and chromite.

Combined basic and ultrabasic settings are represented by the Bushveld and Stillwater complexes. These are large, layered intrusive bodies with an ultramafic lower portion and a mafic upper portion. PGE mineralization is present in both the mafic and ultramafic parts of these complexes. In the Bushveld complex, the PGE-rich Merensky Reef and the UG2 chromitite are thin, but very extensive, layers in the mafic portion, whereas the LG6 chromitite is in the ultramafic portion. In the Stillwater complex in Montana, the PGE-rich J-M Reef is in the mafic portion, and low PGE values occur in chromitite layers in the ultramafic part.

In the Merensky and J-M Reefs of both complexes, PGE are concentrated in stratabound Zones comprising sparse, finely disseminated chalcopyrite, pentlandite and pyrrhotite. PGE occur as PGE sulphides, as As and Te compounds, and in solid solution with pentlandite.

On a world scale, the USSR is the largest PGE producer, followed closely by South Africa, with Canada a distant third. Most of the USSR production comes from the Noril'sk area of Siberia as a by-product of Cu-Ni operations, and palladium dominates over platinum. The Bushveld Complex accounts for nearly all of South Africa's production, and platinum dominates over palladium. Almost all of Canada's PGE production is a by-product from Ni-Cu production at Sudbury. Here, PGE-bearing concentrates are shipped overseas by both Inco and Falconbridge for further processing and refining. At present, there is no primary PGE refining facility in either Ontario or the rest of North America.

Outside of the Sudbury area, most of the thirty-odd PGE prospects and occurrences known in Ontario are in the general

Thunder Bay area. Except for the three discussed below, most of these are at relatively early stages of exploration.

In Ontario, three PGE deposits have identified reserves and are being or have been considered for production. These are the Lac des Iles, Marathon and Crystal Lake deposits. After Stillwater, Montana, which is expected to begin production in 1987, these three northern Ontario deposits are the most advanced prospects in North America.

The Lac des Iles deposit, located 80 km north of Thunder Bay, is held under option by Madeleine Mines Ltd. of Toronto. PGE occur in sparsely disseminated sulphides in gabbro of the Lac des Iles ultramafic/mafic complex. Open pit probable reserves, representing part of the total geological reserves, have been estimated to a depth of 500 ft. as:

6,490,000 tons averaging	0.179 oz/ton total PGE
	0.1% Cu
	0.1% Ni
	0.01 oz/ton Au

The Pd:Pt ratio is in the order of 9:1.

Flotation tests carried out in the 1970's suggest that, although more work is required, the following recoveries might be attained: Pd 75%, Pt 65%, Cu 80% and Ni 65%. Concentrate would likely be sold to Inco at Sudbury.

A 1980 study of economic potential, based on mining up to one million tons per year, suggested that sufficient operating profit could be generated to give the Lac des Iles project a significant, pre-tax value. RPA's order of magnitude assessment, using the same parameters and mid-August 1986 metal prices, suggests that operating profit would be lower in 1986, and that the project would be marginal unless reserves increased significantly to justify a

higher mining rate. Because of rising PGE prices and uncertainty about South Africa, more work and economic studies are justified.

The Marathon deposit is owned by Fleck Resources Inc. of Vancouver and is under option to Teck Corporation. It is located 10 km northeast of Marathon, Ontario. PGE values are associated with a large, low grade, copper deposit in gabbro of the Coldwell Complex. Reserves to a depth of 600 ft. are reported as:

46.9 million tons averaging	0.46% Cu
	0.04% Ni
	0.044 oz/ton Pd
	0.012 oz/ton Pt
	minor Ag, Au, Rh

Preliminary pilot plant tests on bulk samples by Fleck suggest that the following recoveries might be attained: Cu 88.6%, Ni 48%, Pd 82%, Pt 79%. Concentrate would likely be sold to Inco.

A pre-feasibility review of the Marathon deposit in early 1986, based on a 12,500 ton per day mine/mill operation, indicated a satisfactory rate of return, and a feasibility study has been commissioned by Fleck.

The Crystal Lake deposit, held by Great Lakes Nickel Limited, has recently been optioned to Fleck Resources. The property is readily accessible and is located 50 km south of Thunder Bay. A large, low grade Ni-Cu deposit with minor PGE values has been delineated in the Crystal Lake Cabbro, with reported reserves of:

45.6 million tons averaging	0.344% Cu
	0.183% Ni
and in the order of	0.02 oz/ton Pd
	0.006 oz/ton Pt
	minor Rh, Au, Ag

Although studies prior to 1975 were optimistic with regard to underground mining and milling of the Great Lakes Nickel deposit, studies since 1975 have been negative and the property remains on standby status.

Recently, Great Lakes reported minor PGE values in narrow zones above the known sulphide deposit. Further exploration for PGE appears to be warranted. Fleck Resources recently optioned the property.

About 25 other PGE prospects and occurrences in Ontario are at the exploration stage. Some of those presently being explored and which have reported PGE values are: Big Trout Lake, Puddy Lake/Chrome Lake, Reaume Township, Coldwell Complex and several occurrences in the Lac des Iles area.

Outside of Ontario, PGE deposits and prospects exist in other provinces of Canada as well as in Alaska, Montana and Minnesota, U.S.A. Of these, the Stillwater Complex in Montana is the only imminent producer.

Stillwater Mining Co., owned by Chevron Corp., Manville Products Co. and Lac Minerals Ltd., plans to start production from the J-M Reef in mid-1987. Initial mining rate will be 500 tons per day to produce 25,000 oz Pt and 75,000 oz Pd per year, doubling in 1991. Proven reserves, which represent only a small part of the PGE resources in the J-M Reef, are quoted to be 400,000 tons averaging 0.79 oz/ton total PGE.

Other potential North American producers are the Duluth Complex in Minnesota and the Ungava Nickel Belt in northern Quebec. Other important prospects at the exploration stage include Lac Sheen, Quebec; Fox River, Bird River, and Falcon Lake, Manitoba; Wiley Lake and Rottenstone, Saskatchewan; Tulameen, British Columbia; Muskox, Northwest Territories; Salt Chuck and La Perouse, Alaska.

INTRODUCTION

This review of platinum group element (PGE) deposits of Ontario was contracted by the Ontario Ministry of Northern Development and Mines as a result of a proposal submitted to the Metallic Minerals Section of the Minerals Resources Branch by Roscoe Postle Associates Inc. (RPA).

This proposal was prompted by a rapid increase in interest in PGE over the past few years by the Canadian mining industry. This appears to have resulted from an increase in platinum and palladium demand and prices and from increasing uneasiness about long term supply from the Republic of South Africa, who, along with USSR, are the world's largest PGE producers, and hold the bulk of the world's reserves (Figure 1).

Canada's PGE production is as a by-product of Ni-Cu production, and comes almost entirely from the Sudbury basin, with minor output from Thompson, Manitoba and Shebandowan, Ontario. Both Inco's and Falconbridge's PGE production is shipped in concentrate form and refined overseas.

The objectives of this review are to summarize technical data and current status of the main Ontario PGE deposits and prospects; to look at them in the context of world-class PGE deposits; to examine in a preliminary way their potential economics; and to briefly review other PGE deposits in North America.

First, the characteristics of various types of PGE deposits are described, with examples. Then, three major Ontario PGE deposits are described, along with their reported reserves and their potential economics. Finally, other North American PGE deposits are reviewed, along with PGE prospects in other areas in Ontario.

Relative proportions, grade (in g/tonne) and reserves (in millions of oz) of Platinum Group Metals in selected deposits

	Bushveld Complex South Africa						Sudbury		Noril'sk			Stillwater	
	Merensky Reef		UG2		Plat Reef		Canada		U S S R		Colombia	U S A	
	Propn	Reserves*	Propn	Reserves*	Propn	Reserves*	Propn	Reserves	Propn	Reserves	Propn	Propn	Reserves*
Platinum	59	333	42	437	42	160	38	3 4	25	50	93	19	7
Palladium	25	141	35	365	46	175	40	3 6	71	142	1	66 5	23
Ruthenium	8	45	12	125	4	15	2 9	<1	1	2		4 0	1 4
Rhodium	3	17	8	83	3	12	3 3	<1	3	6	2	7 6	2 7
Iridium	1	6	2 3	24	0 8	3	1 2	<1			3	2 4	< 1
Osmium	0 8	5			0 6	2	1 2	<1			1		
Gold	3 2	18	0 7	7	3 4	13	13 5	<1 2				0 5	< 1
Total		**565**		**1041**		**380**		**9**		**200**			**35**
Grade	**8.1**		**8.71**		**7 – 27**		**0.9**		**3.8**			**22.3**	

*Calculated to 1200 metres vertical depth

From "Platinum Group Production from the Bushveld Complex and its Relationship to World Markets"
D L Buchanan November 1979

After Johnson Matthey, 1985

Figure 1

Outside the Sudbury area, there are three deposits in Ontario with published Cu-Ni-PGE reserves which are being or have been considered for production. These are:

- Lac des Iles deposit, Thunder Bay area, under option to Madeleine Mines Ltd.
- Marathon deposit, Coldwell Complex, under option to Teck Corporation.
- Crystal Lake deposit, Thunder Bay area, under option to Fleck Resources Inc.

The main sources of information for this review of Ontario deposits are:

- Publications in professional journals
- Government publications
- Ontario Geological Survey - assessment files and Open File Reports
- The Northern Miner Library File Service
- Ontario Securities Commission documents
- Company files
- Field visits to the Lac des Iles and Marathon properties
- Discussions with Ontario Ministry of Northern Affairs and Mines personnel

GENERAL CLASSIFICATION OF PGE DEPOSITS

It is important to classify PGE deposits into different types, so that common characteristics can be recognized and used for exploration, metallurgical technology, or mining purposes. Most of the world's PGE production comes from just a few types of deposits. A prospective deposit which can be classified as, say, one of the Bushveld types, might then warrant more exploration work.

The general classification adopted in this report primarily follows Cabri & Naldrett's (1984) scheme, with minor incorporation from Naldrett's (1981) classification. Slight modifications adopted in this study should not detract from the other classifications.

Deposits shown as examples in the following classification are PGE producers, past producers, or contain identifiable PGE reserves.

Group I: Sulphide Association

I.A.: PGE Dominant

I.A.1. Merensky Reef-type: *Bushveld, *Stillwater, Great Dyke, Muskox

I.A.2. Platreef-type: Bushveld, Lac des Isles(?)

I.A.3. Hydrothermal-type: Rathbun Lake, New Rambler, Messina.

I.B.: Ni-Cu Dominant

I.B.1 Sudbury-type: *Sudbury

I.B.2 Noril'sk-type:*Noril'sk-Talnakh, Insizwa, Duluth, Crystal Lake

I.B.3 Pechanga-type: Pechanga, Lynn Lake, Kanichee, Shebandowan(?), Thierry(?), Lac des Iles (?)

I.B.4 Kambalda-type: *Kambalda, Yakabindie, Shangini, Alexo, Langmuir #2, Marbridge, Manitoba Nickel Belt, Ungava

I.B.5 Alkaline type: Marathon

Group II: Oxide-Silicate Association

II.1 UG2-type: *Bushveld, Stillwater

II.2 Eastern Bushveld: Onverwacht, Mooihoek, Driekop

II.3 Alpine-type & Placers: NW China, Turkey, N. California, Atlin

II.4 Zoned Ultramafic-type & Placers

II.4a Alaskan sub-type: Good News Bay, Alaska Panhandle, Tulameen, etc.

II.4b Ignali sub-type: Ignali, Chad, etc.

II.5 Kachkanor-type: Guseva Gora, Kachkanor

* World class producers

___ Foreign deposits discussed in this report

_ _ Canadian examples, only most important discussed in this report.

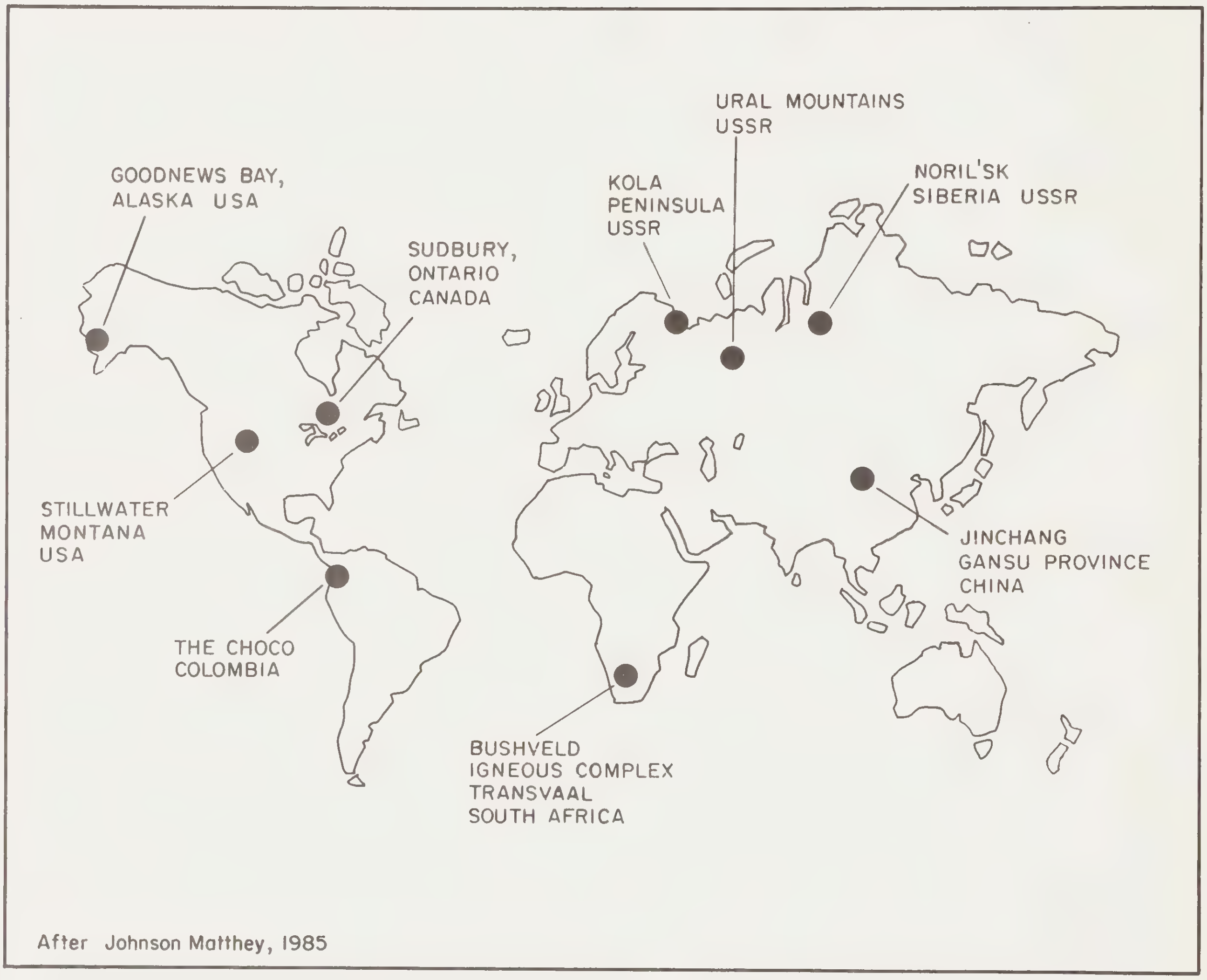
ESSENTIAL CHARACTERISTICS OF PGE DEPOSIT - TYPES

GENERAL DISCUSSION

1. Study of PGE deposits entails literature research into nickeliferous sulphide, chromite, and PGE deposit-classes due to common sharing of both characteristics and metal associations in many representative examples from different deposit-classes. The virtual explosion of published papers covering all three deposit-classes during the last 10-15 years have provided the scientific community with hard data, sound understanding and a conceptual framework of their origin, leading to better exploration models.

2. The platinum group elements comprise Pt, Pd, Ru, Rh, Ir, Os with Pt and Pd dominant, and substantially less of the minor PGE in decreasing order as listed. This report deals virtually entirely with bedrock deposits; placer deposits are only mentioned where appropriate. Placer deposits produce only about 2% of total world production (Jolly, 1978), and the present potential for commercial placer deposits in Canada is deemed to be only minor.

3. Primary production of PGE in the world (Figure 2) is centred in only three countries: USSR, Republic of South Africa, and Canada produce more than 98% of the yearly total world production, with USSR (3.7 million troy ounces, 50%) and South Africa (3.2 million troy ounces, 43%) sharing the lead and Canada (0.35 million troy ounces, 5%) a distant third (estimates, USBM Min. Comm. Summ. 1986). Reserves of total PGE (USBM Comm. Summ. 1986) are dominated by South Africa (970 million troy ounces, 81%), USSR (200 million troy ounces, 17%), USA



World Sources of Platinum Group Metals

Figure 2

(16 million troy ounces, 1.3%), and Canada (9 million troy ounces, 0.75%). Virtually all Soviet and Canadian PGE production is by-product from Ni-Cu mining. Most of the Western World's PGE production comes from mines owned by only 5 companies: Rustenburg Platinum Mines, Impala Platinum (10% Inco), Western Platinum (24.5% Falconbridge), Inco and Falconbridge. Growth in world PGE consumption is expected to be 2.9% per year during the period 1983 to 2000 (USBM Min. Facts & Prob., 1985). U.S. consumption in 1985 was about 2.5 million troy ounces, about one-third of total world production estimated to be 7.4 million troy ounces (USBM Min. Comm. Summ. 1986). Canada produces more PGE than it can consume (Mohide, 1979).

4. Classification schemes for PGE deposits have evolved considerably from groupings on the basis of tectonic setting (Naldrett, 1979), PGE dominant vs. Ni-Cu dominant (Naldrett, 1981), and most recently, sulphide association vs. oxide/silicate association (Cabri & Naldrett, 1984). The scheme adopted in this report combines the 1981 and 1984 classification schemes. Each of the schemes has merit and validity, and represents successive improvement by incorporating new data and understanding. The classification scheme herein merely rearranges previous classifications to best suit the purposes of this study.

5. PGE deposits are genetically associated with basic and ultrabasic rocks. <u>Basic rock settings</u> (somewhat equivalent to tholeiitic, flood basalt, gabbroic magmas) are hosts for PGE camps such as Noril'sk, Sudbury, Duluth, and Crystal Lake. Mineralogically, ores in this setting are characterized by platinum group minerals (PGM) which are compounds of S, Sb, As, Bi and Te, and associated with Ni-Cu sulphides which may be the principal mining product. On the other hand, <u>ultrabasic rock settings</u> (somewhat equivalent to komatiitic magmas and ultrabasic tholeiitic magmas are hosts for PGE camps

such as Kambalda, Ungava, Manitoba Nickel Belt, Onverwacht, Atlin, and Tulameen. Mineralogically, ores in this setting are characterized by native PGE alloys, discrete sulphide minerals, and solid solution of PGE in sulphides, forsteritic olivine, and spinels such as chromite (Jolly, 1978). In these ultrabasic rocks, the grains of native alloys are heavy, dense, physically tough, and relatively chemically inert, commonly giving rise to placer PGE deposits such as in Tulameen, B.C.; Colombia; Urals; Witwatersrand, S.A.; and Goodnews Bay, Alaska. The <u>combined basic rock and ultrabasic rock settings</u> represented by the Bushveld and Stillwater Complexes are stratigraphically layered with an ultramafic lower portion overlain by mafic (gabbroic and anorthositic) upper portion. These large, layered complexes are also characterized by cyclic layering with individual cyclic units usually less than 60 m thick. PGE and chromitite reefs exist in both complexes. The Bushveld hosts the PGE-rich Merensky Reef and UG2 layer in the mafic phase, and LG6 (Steelpoort) chromitite in the ultramafic portion. The Stillwater hosts the PGE-rich H.P. (J-M) Reef in the mafic portion, and G,H chromitite reefs (very low PGE) in the ultramafic portion. In both reef-bearing complexes, PGE are highly concentrated in sparse (0.5-5%), finely disseminated, strikebound Ni-Cu sulphides, and PGE are the primary mining product with Ni, Cu, Au (and Cr in UG2) recoverable as by-products. Mineralogically, the ores in this setting are characterized by PGE sulphide minerals, solid solution in base metal sulphides especially pentlandite, and PGE mineral compounds with As and Te (Cabri & Naldrett, 1984).

6. According to Naldrett and Macdonald (1980), abundance of Ni and Cu (and PGE) in most magmas is sufficient to form significant sulphide deposits, provided that the sulphur content in the magma is enough to produce sulphide supersaturation conditions. The main factors which will

determine the magma's ability to make an economically attractive deposit include the efficiency of PGE concentration in immiscible sulphide droplets in the cooling magma, the volume of magma in contact with liquid sulphide droplets, and the amount of dilution by silicate minerals (timing). Thus, sulphur availability is the key determining factor for nickeliferous PGE magmatic sulphide deposits, and research on this subject has provided credible insights and feasible explanations. The source of sulphur may be largely magmatic (e.g. Kambalda, Merensky Reef, UG2, H.P. Reef, Sudbury) or mainly from country rocks (e.g. Noril'sk, Duluth), or a combination of the two sources.

7. Contamination of mafic/ultramafic magma may cause batch segregation of sulphides, producing rich semi-massive to massive sulphides. Irvine (1975) proposed that silicification of mafic magma induces sulphide saturation conditions in the magma, and that the rich Sudbury ores originated from this process. Irvine (1970) similarly postulated that large, Ni-Cu sulphide concentrations at the base of the Stillwater and Bushveld intrusions may have resulted from silicification (and sulphurization?) in the basal part of the magma by assimilation of country rock. Sulphurization of mafic-ultramafic magmas has become widely accepted to help explain various Ni-Cu (PGE) sulphide deposits occurring at the base of mafic-ultramafic intrusives, e.g. Stillwater, Noril'sk, Duluth, Crystal Lake, Platreef.

8. Many researchers have recognized strong hydrothermal effects with mineralization particularly in the Bushveld, Stillwater, Noril'sk, and Duluth intrusives. Pegmatites, biotite, graphite, potholes, and "fossil fumaroles" have been noted with the Merensky Reef and J-M Reef. Hydrothermal effects have also been identified with the UG2 Reef in the Bushveld and chromitite zones at Stillwater. Whether hydrothermal fluids played a direct

or indirect role in mineralization at Bushveld and Stillwater is equivocal, but a few PGE deposits (e.g. Rathbun Lake, Ontario; Messina, South Africa; and New Rambler, Wyoming) are acknowledged to be products of hydrothermal processes. Naldrett's (1981) classification created a separate Hydrothermal Deposits category.

I.A.I. MERENSKY REEF - TYPE

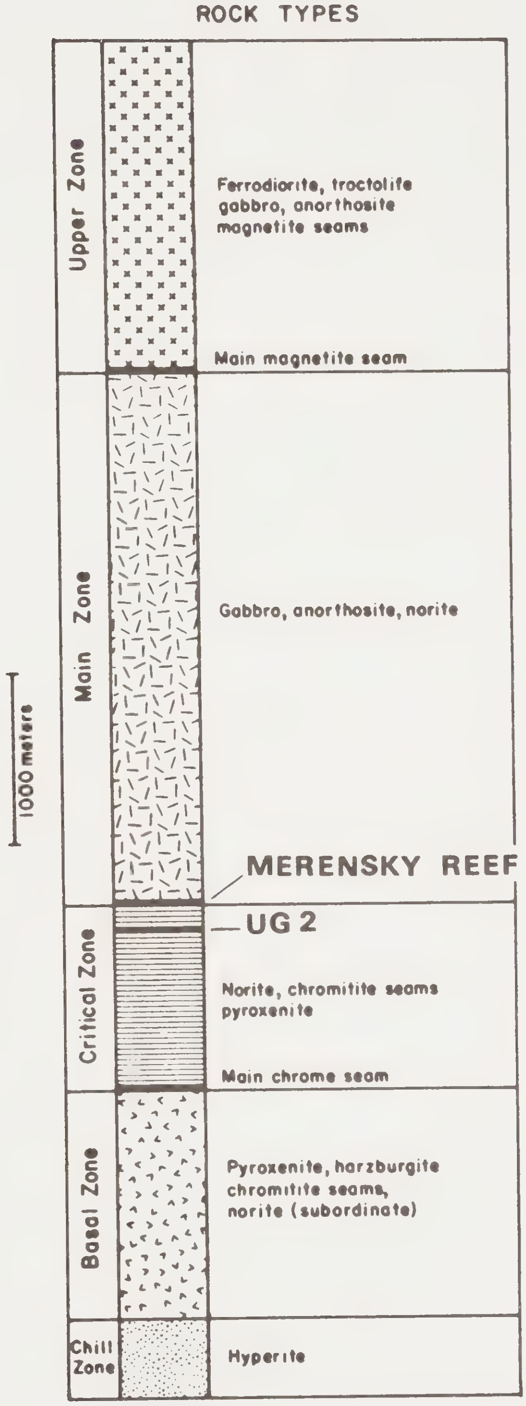
Merensky Reef, Bushveld Complex, South Africa

The Bushveld Complex contains vast economic deposits of PGE, chromite, and vanadium, and the dominant role that politically unstable South Africa occupies as a supplier of these commodities has caused these metals to be classified as strategic metals in North America.

The Bushveld Complex is a 2.1 billion year old layered mafic and ultramafic sill-like intrusion forming an upright, subhorizontal saucer shaped body about 240 x 400 km in plan and 7 to 9 km thick. This very large body likely comprises several intrusions which coalesced as new magma was introduced at successively higher levels in the corresponding magma chambers.

Large, rich mineral deposits formed at separate stratigraphic intervals including PGE, chromite, and vanadium deposits (Figure 3). PGE deposits include the Merensky Reef, UG2, Platreef, and Eastern Bushveld-type deposits, each constituting a separate PGE deposit-type in Cabri & Naldrett's (1984) classification, and similarly discussed separately in appropriate sections of this report.

The Merensky Reef forms a relatively consistent horizon about one metre thick around most of the Bushveld complex, occurring near the upper part of the Anorthosite Series of the Critical Zone (Figure 3), and consists of pegmatitic



Bushveld Stratigraphic Section

After: Sawkins, 1984

Figure 3

feldspathic pyroxenite with thin chromite seams at the top and base, characterized by the Rustenburg section. The pegmatitic pyroxenite, biotite, graphite, and potholes may be attributed to hydrothermal activity related to the development of the mineralized horizon. PGE accompany pyrrhotite, chalcopyrite and pentlandite interspersed in amounts of 1 to 5% within the two chromitite layers and intervening pegmatite, and closely follow Ni-Cu distribution.

Ore grade for Merensky Reef deposits range from 4 to 12 g/t total PGE, averaging 8.1 g/t in the Western Bushveld (Cabri & Naldrett, 1984) with modest Ni, Cu, and Au credits. "Representative ore" from Merensky Reef analyzed by the U.S. Bureau of Mines grades 0.154 oz/ton Pt and 0.066 oz/ton Pd. (USBM Min. Facts & Problems 1985). Total Merensky Reef reserves to a depth of 1200 metres are stated to be 17,500,000 kg (562.6 million troy ounces) PGE and Au (Buchanan, 1979).

Where mined, the Merensky Reef is about 0.8 to 1 metre thick. It is mined at the Rustenburg, Impala, and Western Platinum Mines. Pt:Pd ratio is 2.5:1.

Platinum group minerals vary significantly in different parts of the Merensky Reef, but the predominant minerals are cooperite PtS, braggite (Pt,Pd)S, Pt-Fe alloy, sperrylite $PtAs_2$, laurite RuS_2, moncheite $PtTe_2$, michenerite PdBiTe, merenskyite $PdTe_2$, and kotulskite PdTe (Cabri & Naldrett, 1984). Important amounts of PGE occur as solid solution or submicroscopic grains within the Ni-Cu sulphides.

South Africa presently accounts for about 85% of the world's platinum production (Market Report, Aug. 1, 1986) mainly from the Merensky Reef. Important contributions from the UG2 reef began at Rustenburg in 1984 and Western Platinum Mines in 1985 and overall, will increasingly supplement Merensky Reef production in subsequent years.

I.A.2 PLATREEF - TYPE

Platreef, Bushveld Complex

The Platreef was one of the first PGE deposits discovered and mined in South Africa. Mining of the Platreef started in 1926 but lasted for just a few years as interest and activity shifted to the Merensky Reef in the Rustenburg area.

The Platreef occurs in the Potgietersrus limb, the northern extension of the Bushveld Complex. Only rough stratigraphic correlations can be made with other sections of the Bushveld Complex, and the Platreef is only shown to lie within the cyclically layered sequence. Platreef mineralization (Naldrett, 1981) is diffuse and erratic, consisting of sulphide blebs and stringers, sporadically developed in a loosely defined zone roughly measuring 60 km strike length and up to 200 m thick.

The Platreef is hosted by pyroxenite and harzburgite. The mineralization always occurs near or at the base of the intrusion, and ores are best developed where dolomite and banded ironstone are in contact with the intrusion and form abundant inclusions within the intrusion. Sulphides may extend up to 30 m into the dolomitic country rock. Various researchers have attributed the development of sulphides in the Platreef to localized effects in the Bushveld magma caused by direct interaction with the floor rocks.

Total PGE grade estimates range from 7 to 27 g/t (Buchanan, 1979), probably reflecting the erratic, inhomogeneous nature of the ore and limited ore definition drilling. Cabri & Naldrett (1984) give an average grade of about 6.3 ppm. Total PGE reserves are 380 million ounces, constituting 42% Pt, 46% Pd (Figure 1). Platreef ore also contains important amounts of Ni and Cu. Recovered grades estimated by Von Gruenewaldt (1977) are 0.36% Ni and 0.18%

Cu. Gold may constitute 3.4 weight percent of total precious metals.

PGE show strong correlation with Cu and Ni, and PGM's occur as inclusions in chalcopyrite (Cabri & Naldrett, 1984). PGM's in the Platreef comprise: major cooperite PtS, braggite (Pt,Pd)S, sperrylite $PtAs_2$, vysotskite PdS, and kotulskite PdTe; intermediate isomertieite $Pd_{11}(As,Sb)_4$, merenskyite $PdTe_2$; and minor Pt-Fe alloys and moncheite $PtTe_2$. Solid solution of Pd in pentlandite is also reported.

The attractiveness of Platreef-type mineralization has drawn renewed interest by several companies including Johannesburg Consolidated Investment Company (Naldrett, 1981), although no new mines are opening as yet. Part of the appeal is the ability to mine part of the ore by open cut methods.

I.A.3 HYDROTHERMAL - TYPE

Rathbun Lake, Ontario

Hydrothermal-type PGE deposits tend to have exceptionally high Pd and Pt values, but thus far appear to be too small to merit significant status as a resource for PGE. But their importance may be judged by the role that hydrothermal fluids play as a PGE metal carrier, and in upgrading or enhancing some of the other types of PGE deposits, a theme adopted by some researchers.

Hydrothermal-type deposits identified in the literature comprise Rathbun Lake, Ontario (Rowell & Edgar, 1985), New Rambler, Wyoming (McCallum et al, 1976), and Messina, South Africa (Mihalik et al, 1974). The Rathbun Lake deposit is discussed below because its reference deals of all three deposits and contains comprehensive details. All three

deposits share several common characteristics, except for host rocks. The New Rambler deposit is hosted by hydrothermally altered metadiorite and metagabbro, whereas the Messina deposit lies within hydrothermally altered high grade metamorphic rocks. Average grade of 21 cupriferous samples from New Rambler comprises 71 ppm Pd, 2.9 ppm Pt, 0.02 ppm Rh. One sample of Messina cupriferous rock contained 116 ppm Pd, 24 ppm Pt, 1.3 ppm Rh, 0.6 ppm Ru, 2.5 ppm Ir, 0.6 ppm Au, and 152.4 ppm Ag.

The Rathbun Lake deposit consists of a small Cu-Ni sulphide deposit hosted by a tholeiitic gabbronorite stock (Nipissing-type, Middle Proterozoic age) located about 50 km northeast of Sudbury. The gabbronorite has been hydrothermally silicified, chloritized, and saussuritized. The sulphide body measures only about 12 m x 3 m, and consists primarily of chalcopyrite and pyrite, with accessory amounts of millerite, arsenopyrite, violarite, magnetite, and PGM.

Studies show that most of the PGM at Rathbun Lake are enclosed within gangue silicate minerals suggesting that most of the PGM crystallized independently of the sulphides. Mineralogically, Pt and Pd bismuthotelluride minerals have been identified, in common with New Rambler and Messina. On the basis of 11 samples, the Rathbun Lake deposit averages 20.8 ppm Pd, 10 ppm Pt, 3 ppm Au. Other PGE are extremely low.

Oxygen isotope studies indicate that the mineralizing fluid was partly meteoric in origin, and was introduced into the host rocks at a temperature between 300 and 400^{o}C.

I.B.1 SUDBURY - TYPE

Sudbury, Ontario

The Sudbury Igneous Complex is the host for about 50 mines (producers and past producers) which dominated world nickel production for several decades. Its dominant position has eroded steadily during the last 20 years. Other important co-products and by-products include copper, cobalt, selenium, tellurium, platinum, palladium, gold, and silver.

The Sudbury Igneous Complex is a basin or funnel shaped layered intrusive forming an elliptical ring about 60 km long and 27 km across, and varies from 1.5 to 6 km thick on bedrock surface. The intrusive has been dated at 1.85 billion years, and is in contact with Archean rocks on its north side and early Proterozoic Huronian rocks on its south side. The basin is filled with sedimentary rocks of the Whitewater Group, including the basal Onaping Formation which may represent "fallback breccia" originating from meteorite impact.

According to the meteorite impact theory, the Sudbury igneous event is considered to have been triggered by shock waves penetrating down to the mantle causing melting and upward migration along fractured rocks below the basin. intrusive rocks comprising lower norite, upper micropegmatite and granophyre were immediately followed by intrusion of sublayer norite along the norite-basement contact, the whole sequence of intrusives penetrating the unconformity between the basement rocks and Onaping Formation.

Compositionally, the Sudbury Intrusive is gabbroic, and in contrast with Bushveld and Stillwater, lacks ultramafic basal rocks and small scale cyclic layering. Instead, Sudbury has phase layering characterized by the thick norite-micropegmatite-granophyre phase layers. The lack of

small scale layering at Sudbury has been attributed to massive assimilation of silicic country rock into the magma giving rise to viscous behaviour inhibiting conditions for small scale layering. This silicification phenomenon has also been proposed to explain the origin of massive Ni-Cu orebodies at Sudbury (Naldrett, 1981).

Massive Ni-Cu sulphide deposits with minor but recoverable PGE and Au are associated with Sublayer Norite particularly at its base (and into Footwall Breccia at embayment structures) along the northern and southern rims of the Sudbury basin, and with radial and concentric Offset Dikes related to Sublayer Norite.

The Sudbury ores produce Ni and Cu as co-products, and PGE as by-products from orebodies containing about 1 gm PGE per tonne (Cabri & Naldrett, 1984). The Pt:Pd ratio for Sudbury ores is about 1:1. PGE production has been continuous for about 50-60 years, with important contributions from higher grade deposits such as Frood (Bateman, 1956, reports about 0.08-0.09 oz total PGE/ton) and Levack West (Naldrett et al, 1982, reports 2710 - 9318 ppb total PGE).

Another type of Sudbury ore, Cu-rich stringer ore, such as at Levack West, occurs in basement rocks and contains unusually high PGE and Au values. This ore-type has recently given rise to exploration work apparently resulting in successes at Sudbury (verbal communication, anonymous).

Eighteen platinum group minerals have been identified in Sudbury ores, the main minerals comprising sperrylite $PtAs_2$, michenerite PdBiTe, moncheite $PtTe_2$, and merenskyite $PdTe_2$ (Cabri & Naldrett, 1984). Pt, Pd, and Rh also occur as solid solutions in some of the arsenides and sulpharsenides.

The Sudbury deposits achieved important world status for

PGE production after the relatively rich Frood Mine began production, followed by other PGE-rich deposits such as Levack West. In recent years, Canada's share of world PGE production (almost wholly from Sudbury) has varied between 9% (Mohide, 1979) and 7%. Sudbury is the third largest PGE camp in the world.

It is interesting to note that Canada (Sudbury) was the world's leading producer of PGE during the period 1933-1953, and produced more than 50% of the world's mine output during World War II (Mohide, 1979).

Canada (mainly Sudbury) produced about 350,000 troy ounces total PGE in 1985, and has reserves of about 9,000,000 troy ounces (USBM, Min. Comm. Sum. 1986). Production is mainly from Inco and Falconbridge in Sudbury, although minor PGE production comes from Inco's mines at Thompson, Manitoba and Shebandowan, Ontario.

I.B.2 NORIL'SK - TYPE

Noril'sk Region, USSR

The Cu-Ni deposits in the Noril'sk area were first exploited in 1920, and successive discovery of the Talnakh, Oktyabr'sk, and North Kharayelakh Cu-Ni ores have provided this region with the largest Cu-Ni reserves in the USSR (Smirnov, 1977). These ores contain very high PGE, and even though by-product PGE production is tied to Cu-Ni production, the USSR (mainly Noril'sk region) has been the leading supplier of PGE in the world during the last few years. The USSR and South Africa dominate world PGE production, and their vast, high grade reserves guarantee a similar dominant role in the future.

The Noril'sk and related ore fields are associated with early to middle Triassic tholeiitic mafic intrusives which

were feeders or conduits for flood basalts, and served as centers of igneous activity and Cu-Ni-PGE mineralization. Four cycles of flood basalt-mafic intrusive activity are recognized, but Cu-Ni mineralization is associated with only the third igneous cycle.

The Noril'sk, Talnakh, Oktyabr'sk, and North Kharayelakh camps are located along the same deep-seated fault structure, the Noril'sk-Kharayelakh fault, and have similar geologic settings and ore controls. The Noril'sk-Kharayelakh fault is located near the extreme northwestern margin of the Siberian Platform, and is parallel and close to the major fault zone which defines the eastern edge of the northerly-trending West Siberian Lowlands. The West Siberian Lowlands and its northeasterly and northwesterly-trending arms represent a radiating system of grabens (aulocogenes) which converge west of Noril'sk.

The mafic, subvolcanic intrusives radiate upward and outward from igneous loci, along the Noril'sk-Kharayelakh fault, and penetrate Lower Paleozoic marine argillaceous sediments, Devonian evaporites, Carboniferous limestone, coal and continental sediments. During its ascent, the mafic magma ingested abundant sulphate from the evaporite sequence, along with coal and other wallrocks adjacent to its conduits. The occurrence of sulphide orebodies and their mineralogical character are deemed to reflect this assimilation of sulphate and coal into the mafic magma. Naldrett (1981) has postulated that sulphate was reduced by coal, allowing S and Fe to form liquid sulphide droplets in the magma. The droplets then served as efficient collectors of Cu, Ni, and PGE.

Mineralized intrusions in the Noril'sk region are all fully differentiated intrusions with picrite in the basal portion overlain successively by picritic dolerite and a more felsic phase. The intrusions are sill-like, lens or trough shaped in cross-section, and measure up to 12 km x 2 km x 350

m. Cu-Ni-PGE mineralization (Genkin et al, 1981) is developed in the picritic phase, and downward into the basal contact and beyond into altered and metamorphosed sedimentary country rock.

Orebodies form persistent zones as disseminated and massive ore comprising mainly pyrrhotite, pentlandite, and chalcopyrite in picrites chromite is also enriched in picrite, and as disseminated, breccioid, and massive veins in the altered footwall sediments.

PGE occur in all types of ore but highest concentrations occur with high grade copper phases in the lower part of massive sulphide bodies and massive Cu-rich veins which transgress the lower part of massive sulphide, across the footwall contact into metasomatically altered footwall metasediments. The strong increase in Cu/Ni ratio and high PGE concentration in Cu-rich ore have been explained by fractional crystallization from an immiscible sulphide melt (Naldrett & Macdonald, 1980; Genkin et al, 1981), the Cu-rich melt crystallizing last.

Disseminated ores comprise about 70% of total ore, massive ores about 10%, and vein ores about 13% (Smirnov, 1977). Overall average grade for PGE ores from the Noril'sk region is 9.6 g/t (Cabri & Naldrett, 1984), and Pt:Pd ratio is about 0.4.

The PGE mineralogy of Noril'sk ores is known for its considerable diversity, particularly in Cu-rich ores. The PGM are directly associated with pyrrhotite, pentlandite, chalcopyrite, cubanite, magnetite, and chromite. Cabri & Naldrett (1984) provide a list of major PGM comprising Pt-Fe alloys, sperrylite $PtAs_2$, polarite Pd(Bi,Pb), secondary PGM stannopalladinite (Pd_5Sn_2Cu), cabriite Pd_2SnCu, taimyrite $Pd_9Sn_4Cu_3$, plumbopalladinite Pd_3Pb_2, and minor PGM michenerite PdBiTe, moncheite $PtTe_2$, cooperite PtS, and vysotskite PdS. Solid solution of Pd in

pentlandite, and Rh in pyrrhotite are also listed.

The USSR produces about two-thirds of the world's palladium, virtually entirely from the Noril'sk region. Total PGE reserves for USSR (mainly Noril'sk region) is 190 million troy ounces (USBM Min. Facts & Prob. 1985).

I.B.3 PECHANGA - TYPE

Pechanga, USSR

The Pechanga-type platiniferrous Ni-Cu deposits are associated with tholeiitic mafic to ultramafic layered intrusive sills in Precambrian greenstone belts, and likely represent igneous activity cogenetic with tholeiitic mafic volcanism early in the development history of an orogenic belt. Ni-Cu deposits at Lynn Lake, Manitoba, and Kanichee, Temagami area, Ontario, are two other examples from this setting, along with numerous other deposits.

The Pechanga district is located at the extreme northwestern end of the Kola Peninsula, USSR, and is hosted by early Proterozoic volcanic rocks. The mineralized sills show phase layering from basal peridotite to pyroxenite and gabbro, with mineralization largely confined to serpentinized basal peridotite. Ore types comprise disseminated ores in the peridotite becoming higher grade toward the base, breccia ores which cut the basal peridotite and merge into disseminated ore, and veinlet ore in country rock schist. Total PGE content in the ore is very low, usually much less than 1 ppm (Cabri & Naldrett, 1984), although Gorbunov (1968) states ore may contain 0.6 ppm Pt and 0.5 ppm Pd.

Mineralogically, PGM include sperrylite $PtAs_2$, Pt-Fe alloys, and michenerite PdBiTe as major species. Ni and Cu are major co-products, whereas PGE are minor by-products.

I.B.4 KAMBALDA (KOMATIITE) - TYPE

Komatiitic lavas and sills host numerous nickeliferous sulphide deposits with small but significant by-product PGE. Important past production of nickel, from various camps particularly in Canada and Australia, and much greater future nickel production will likely come from this deposit class. Total PGE grade for komatiitic deposits ranges from about 0.1 to 1 ppm (Cabri & Naldrett, 1984), somewhat similar to Sudbury.

Komatiitic rocks are common in the early stages of formation of Precambrian greenstone belts, and are characterized by their very high MgO content. Komatiitic lavas are most common and best developed in the Archean, where MgO values greater than 20% by weight are typical, and distinctive spinifex texture is commonly present in lavas. Komatiites are much less common in the Proterozoic, and MgO tends to intermediate, about 12 to 20%. Komatiites are uncommon in the Phanerozoic. Adopting a strict definition of komatiites, true komatiites are virtually restricted to the Archean. In the komatiite settings both lava flows and subvolcanic sills may be mineralized.

Komatiitic nickelferous sulphide deposits may be subdivided into 3 groups (Naldrett, 1981a):

Group 1: Small, high grade deposits, 1 to 5 million tonnes, grading 1.5-3.5% Ni. Deposits located at the base of komatiite flows. Examples include Kambalda, Langmuir, Marbridge.

Group 2: Medium size, medium grade, 10-40 million tonnes, 1.5-2.5% Ni. Deposits located at base of <u>intrusives</u> which may be feeders for flows. Examples include

Ungava, Manitoba Ni belt, Shangani (Zimbabwe), Perseverence (Australia).

Group 3: Very large, low grade, 100-250 million tonnes, 0.6% Ni. Deposits comprise finely disseminated sulphides in dunitic lenses which may be possible feeders for lavas. Examples include Dumont, Quebec; 6 mile, Mt. Keith, Yakabindie, Australia.

Nickeliferous sulphide deposits in Groups 1 and 2 are mainly economically viable, but deposits in Group 3 are generally too low grade for mining.

Nickeliferous sulphides in Groups 1 and 2 are commonly zoned. Finely disseminated sulphides occur well within the flow/intrusive; connected, net textured sulphides enclosing silicate grains occur toward the base; and massive sulphides occur at the footwall contact. Net textured sulphides and massive sulphides commonly constitute ore, whereas disseminated sulphides rarely constitute ore.

Sulphides from komatiite-type magmas have relatively low (Pt + Pd): (Ru + Ir + Os) ratios compared to gabbro/flood basalt magmas. This feature is a reflection of relatively low Pt and Pd content and correspondingly higher Ru, Ir, and Os contents in komatiitic magmas. The Katiniq and Donaldson West deposits, Ungava, contain exceptionally high PGE values compared to other deposits of the komatiite class, along with Ni, Cu contents and might be economically viable if located near infrastructure.

Very little information on PGM in komatiites exists in the literature. The Kambalda deposits contain sperrylite $PtAs_2$, Pd melonite and Pd-Bi tellurides, associated with the main ore minerals pyrrhotite, pentlandite, pyrite, magnetite, and minor chalcopyrite, chromite, millerite, and violarite.

The Kambalda deposits, Western Australia, are typical of nickel sulphide ores of the komatiite association. Numerous small, high grade deposits occur at the base of komatiite flows, and the north-northwesterly trend of ore shoots appear to be controlled by a system of faults in a structural trough. Naldrett (1981a) postulates that footwall irregularities caused by the faults acted as riffles, trapping nickeliferous sulphides as the lavas moved across the footwall irregularities. Pre-mining reserves for 24 ore shoots were stated to be 31 million tonnes, grading 3.6% Ni, 0.29% Cu (Naldrett, 1981b). PGE grades were not given.

Naldrett (1981a,b) postulates that komatiitic magmas were saturated with sulphur at the time of extrusion, and that sulphides and contained metals were concentrated from a much larger volume of magma derived from the mantle.

II.1 UG2 - TYPE

UG2, Bushveld, South Africa

The UG2 layer contains the single largest concentration of PGE in the world (Naldrett, 1981a) and economic exploitation begun only in 1984 will continue to be accelerated, contributing substantially to world PGE supply.

The UG2 chromitite layer occurs in the upper part of the Anorthosite Series of the Critical Zone, stratigraphically below the Merensky Reef (Figure 3), the stratigraphic interval varying from 30-400 m in different sectors of the Bushveld Complex. The thickness of the UG2 layer varies between 60 and 100 cm (average 80 cm), and is a virtually continuous unit in the Bushveld Complex.

The UG2 chromitite layer is just one of many chromitite layers, including the LG6, occurring at or near the base of individual cyclically layered units in both the Anorthositic

Series and Pyroxenite Series of the Critical Zone. Its conditions of formation were likely similar to the Merensky Reef, sharing features such as association with pegmatite, presence of potholes, association of PGE with base metals, and possible hydrothermal effects.

Average grade for UG2 ores is about 7 ppm (Cabri & Naldrett, 1984), although this can be broken down into the northeastern sector grading 8.34 ppm total PGE + Au (Naldrett, 1984, from Gain, 1980), the southeastern sector grading 6-7 ppm total PGE + Au, and the southwestern sector grading 4-5 ppm total PGE + Au (McLaren, 1978). Pt:Pd ratio is about 1.2:1 Gain (1980), provides details on grades of the UG2 in the northeastern sector: Pt 3.3 ppm, Pd 3.29 ppm, Ru 0.92, Rh 0.57 ppm, Ir 0.30 ppm, Au 0.08 ppm, Ni 0.157%, Cu 0.033%.

Total PGE reserves for UG2 have been estimated to be between 800 and 1,350 million ounces (Johnson Matthey, 1986). Chrome is a co-product of UG2 mining whereas nickel and copper are by-products. Total PGE grades for UG2 and Merensky are somewhat similar, but Rh is about three times greater in UG2, and usage of Pt and Rh in three-way autocatalysts in proportions approximating the UG2 ore may make mining of the UG2 even more attractive.

PGM of UG2-type ores (Cabri & Naldrett, 1984) comprise: major laurite RuS_2, cooperite PtS, braggite (Pt,Pd)S, Pt-Rh-Cu sulphide; secondary Pt-Pb-Cu sulphide, Pt-Fe alloy; and minor vysotskite PdS. PGM are characteristically very fine grained and show variability vertically and laterally in the UG2 layer. Problems in treating high chromium ore have been overcome, and flotation has been shown to be a suitable recovery method.

Western Platinum commissioned the first plant exclusively designed for treatment of UG2 ores in 1984, beginning with a mining rate of 58,000 tonnes per month and increasing to

78,000 tonnes per month by September, 1986 (Johnson Matthey, 1986). Rustenburg Platinum Mines began mining the UG2 at Union Section in 1985. Companies mining the Merensky Reef are in a favourable position because both the Merensky Reef and UG2 layer can be mined from the existing operations. Continued and escalated PGE production from UG2 can be expected in the future.

II.2 EASTERN BUSHVELD - TYPE (Dunite Pipes)

Onverwacht, Bushveld, South Africa

Platiniferrous dunite pipes occur in both the eastern and western sectors of the Bushveld Complex and are noted for containing spectacular grades to over 2,050 ppm total PGE (Cabri & Naldrett, 1984).

Only three pipes in the eastern Bushveld, comprising Onverwacht, Mooihoek, and Driekop have had mining and geologic studies, in particular Onverwacht. The dunite pipes are discordant with the Bushveld stratigraphy transecting the LG6/Steelpoort chromitite, and are composed of a central Fe-rich dunite core enclosed within an envelope of Mg-rich dunite.

The Onverwacht orebody comprised a central mineralized core 8 m in diameter (other pipes range up to 18 m in diameter), averaging over 31 ppm Pt, surrounded by a 1 m wide shell ranging from 15 to 30 ppm Pt. Average grade for the mine was between 9 and 11 ppm Pt.

Mineralogically, the Eastern Bushveld-type ores are predominated by Pt-Fe alloys (50% by volume PGE), often intergrown with chromite, and sulphidic PGM are rare. Sperrylite $PtAs_2$ and geversite $PtSb_2$ represent about 30% of the PGM, and hollingsworthite (Rh, Pt, Ru, Ir) AsS and irarsite IrAsS account for 15%.

The mineralized dunite pipes are small bodies of limited extent, relatively PGE-rich but insignificant relative to world reserves.

II.3 ALPINE (OPHIOLITE) - TYPE & DERIVED PLACERS

Podiform chromitite deposits containing low level PGE occur in many parts of the world in Phanerozoic tectonic belts. These magmatic segregation chromitite deposits tend to be small, disjointed bodies or pods which by their large number of deposits cumulatively supply about 55% of the world's chromite demand (Duke, 1983). However, the very low PGE contents (up to 0.9 ppm) and depleted Pt, Pd contents relative to Os, Ir, Ru contribute essentially insignificantly to world PGE production.

Ophiolite complexes represent portions of oceanic crust and uppermost mantle tectonically emplaced in the solid state onto or into the mobile belts along continental margins. Podiform chromitite bodies are found in the basal dunite/pyroxenite portion of complete ophiolite sequences, or in isolated ultramafic blocks in melange where the ophiolite package has been broken into slices.

Examples of ophiolitic platiniferous chromitite deposits are numerous, the best known occurring in NW China, Papua New Guinea, Oman, Cyprus, Greece, Turkey, USSR, Oregon, California, and British Columbia. In some cases, these deposits became economic because weathering of protore has released chromite to form placer deposits.

PGM in these deposits are characteristically dominated by Ru - Os - Ir native alloys such as rutheniridosmine, iridosmine, and osmiridium, although highly serpentinized deposits contain sulphides and sulpharsenides such as laurite RuS_2, irarsite IrAsS, and platarsite PtAsS.

II.4. ZONED ULTRAMAFIC - TYPES AND DERIVED PLACERS

These zoned ultramafic bodies are associated with several historically important placer camps, grading up to 3 ppm total PGE (Cabri & Naldrett 1984) including Goodnews Bay, Alaska, and Choco, Colombia. Tulameen, British Columbia also is known for its placer PGE. World-wide placer PGE production presently continues, but is insignificant when compared to world production. The Goodnews Bay placer operation closed in 1982.

Large intrusives in this class show a crude concentric zoning consisting of a dunitic core and successive shells of olivine clinopyroxenite, magnetite-rich clinopyroxenite, and hornblendite. Irvine (1974) emphasizes the alkalic character of this intrusive type. PGE are very irregularly dispersed, but tend to be enhanced in the dunitic core along with chromite segregations (Cabri & Naldrett, 1984).

These magmatic segregation ores are sulphide poor, chromite rich, and magnetite may occur in economically interesting amounts. Platinum is the dominant PGE, and PGM comprise largely Pt-Fe alloys, and secondarily platiniridium.

II.4a Alaskan sub-type

Zoned ultramafic intruded in active orogenic zones. Examples include Goodnews Bay, Alaska; Alaska Panhandle; Choco, Colombia; Tulameen, British Columbia; U.S.S.R.; etc.

II.4b Ignali sub-type

Zoned ultramafic intruded in stable platform. Examples include U.S.S.R., Chad, etc.

II.5 KACHKANAR - TYPE AND DERIVED PLACERS

The Guseva-Gora titanomagnetite magmatic segregation deposits occur in the Kachkanar mafic-ultramafic intrusive, U.S.S.R. (Cabri & Naldrett, 1984). The wehrlite-clinopyroxenite intrusives occur in an active orogenic zone. PGE are recovered as a by-product of titanomagnetite mining, both in bedrock orebodies and in derived placers. PGM are characterized by Pt-Fe alloys and less platiniridium (Ir,Pt) and osmiridium (Ir,Os), although vysotskite (PdS) occurs in restricted zones of hydrothermal remobilization. PGM in placers are the same as in bedrock, except native osmium is chemically removed during placer formation. Grade and reserve data are unavailable.

ONTARIO PGE DEPOSITS

FRAMEWORK FOR ONTARIO DEPOSITS

Virtually all of the present production of PGE in Ontario is centred in the Sudbury Complex, where 33 past and present producing mines are located (Ontario Mineral Deposits Inventory). The Sudbury-type deposits are unique to the Sudbury Complex, and have been discussed in the previous section.

Other past producers of PGE in Ontario are of the Kambalda-type (Alexo, Langmuir, Marbridge) and Pechanga-type (Kanichee, Shebandowan, Thierry).

Other PGE deposit-types in Ontario include Noril'sk-type (Crystal Lake), Alkaline-type (Marathon), Merensky-type (Big Trout Lake, perhaps Pechanga-type), Hydrothermal-type (Rathbun Lake), Alpine-type (Puddy/Chrome Lakes), and Platreef-type (Lac des Iles; perhaps Pechanga-type or Alaskan sub-type).

Outside the Sudbury area, 20 of the 27 prospects and occurrences listed in the Ontario Mineral Deposits Inventory are located in the Thunder Bay area. The Thunder Bay area appears to be a distinct PGE petrologic province, and in part at least reflects tectonic controls for mafic/ultramafic magmatism along deep-seated aulocagene structures.

The three most advanced Ontario PGE deposits are described in the following sections. These are deposits with identified reserves which are being or have been considered for production. Other PGE occurrences and prospects in Ontario are then briefly described. Locations of the important PGE deposits and occurrences are shown in Figure 4.

PGE Occurrences in Ontario

Legend

1 BIG TROUT LAKE
2 PUDDY - CHROME
3 CRYSTAL LAKE
4 SHEBANDOWAN
5 LAC DES ILES
6 MARATHON

PALEOZOIC
GRENVILLE PROVINCE
SOUTHERN PROVINCE
SUPERIOR PROVINCE

Figure 4

LAC DES ILES

Property Location and Infrastructure

The Lac des Iles property is currently under option to Madeleine Mines Ltd., a member of the J. P. Sheridan group of companies of Toronto, from the Platinum Group Ltd., another Sheridan company. The property is located about 80 km north of Thunder Bay in northwestern Ontario, just south of Lac des Iles. Access is via Highway 17, 90 km west from Thunder Bay, then 50 km northeast on gravel logging road and bush road to the property. In July 1986, the last few km of the bush road were being upgraded for direct vehicle access to the deposit. Alternate access is by float-equipped aircraft landing on Lac des Iles.

Although there is no mining in the immediate area, the Lac des Iles property is within commuting distance of communities west of Thunder Bay, a major Great Lakes port, railway centre and population centre.

The nearest hydroelectric power line is along Highway 17, some 50 km south. There appears to be sufficient water, sand and gravel in the immediate area of the PGE deposits for any possible future operations.

History

The early exploration history of the Lac des Iles property is summarized below, after Clark (1980) and Pye (1968).

1933 - geological mapping by F. Joliffe, resulting in gold prospecting activity.

1958 - aeromagnetic survey and claim staking by F. H. Jowsey Limited.

1959 - diamond drilling by F. H. Jowsey Limited,

north part of Lac des Iles, no commercial values.

1963 - prospecting by W. Baker and G. Moore discovered copper-nickel sulphides south of Lac de Iles.

1963-64- staking by Gunnex Limited followed by geological mapping, geochemistry, ground geophysical surveys and diamond drilling. Eight sulphide zones were located, some of which contained palladium and platinum values.

1964-65- geological mapping by E. G. Pye, published in Geological Report 64 (1968, with Map 2135).

1966 - Anaconda American Brass Limited option from Gunnex, further diamond drilling.

In 1973, the Lac des Iles claims were staked and optioned by Boston Bay Mines Limited, a J.P. Sheridan company. Diamond drilling encountered PGE values with low copper-nickel concentrations, and a new mineralized zone, the Roby Zone, was discovered.

In 1975, the property was optioned by Texasgulf Ltd. and an extensive diamond drilling program was carried out. The option was dropped and the property reverted to Boston Bay in 1976. One deep hole was subsequently drilled by Boston Bay.

Together, Texasgulf and Boston Bay drilled 117 holes for a total of 64,356 ft. In 1980, The Sheridan Platinum Group Ltd. purchased the Lac des Iles claims from Boston Bay and filed a preliminary prospectus with the Ontario Securities Commission. A qualifying report by Glenn R. Clark, P.Eng., dated August 4, 1980, contained reserve estimates, a preliminary open pit design, results of metallurgical testing, estimates of capital and operating costs, and a preliminary economic analysis. The Clark report is the best publicly available source of data on Lac des Iles, and is used extensively in the present review.

The Sheridan Platinum Group underwriting was not completed, due to a drop in palladium and platinum prices in 1981. The company name was changed subsequently to The Platinum Group Mines Ltd.

In 1985, the Ontario Geological Survey commenced mapping of the Lac des Iles area and studies of the PGE-Cu-Ni mineralization (Sutcliffe and Sweeney, 1985; Macdonald, 1985). Sutcliffe and Sweeny's work is continuing in 1986.

In April 1986, Madeleine Mines optioned the Lac des Iles property from The Platinum Group Mines Ltd. It is our understanding that the Clark report is being updated, and that diamond drilling, stripping, sampling and upgrading of the access road are planned for 1986. In mid-July 1986, the first drill hole was in progress.

Geological Setting

The Lac des Iles complex is one of several basic/ultrabasic intrusive complexes surrounded by granitic rocks northwest of the Max Lake-Legris Lake greenstone belt. All rocks are Archean in age, except for local, uneroded remnants of younger Keweenawan diabase sills, one of which outcrops south of the Roby Zone.

The Lac des Iles complex is shaped like a tadpole, 20 km north-south and up to 4 km wide, with the bulbous northern part centred on Lac des Iles. The northern part comprises layered peridotite, pyroxenite, anorthosite, gabbro, websterite, and their altered equivalents, including serpentinite. Recent mapping by Sutcliffe (1985) shows this northern part to comprise two coalesced intrusive bodies, each concentrically zoned.

The southern part comprises two mafic intrusives: the Eastern Gabbro and the Western Gabbro. The Eastern Gabbro comprises medium-grained gabbro to norite and is oxide-rich

and sulphide-poor. The Western Gabbro is coarser grained, locally pegmatitic, layered, and consists of 70% gabbro, 20% norite, and minor clinopyroxenite and anorthosite. Only the Western Gabbro contains Cu-Ni and PGE mineralization. The Western Gabbro was intruded first, followed by the Eastern Gabbro and finally the northern intrusive bodies.

The Lac des Iles deposit may be Platreef-type, is probably of the Pechanga-type, or Alaskan sub-type.

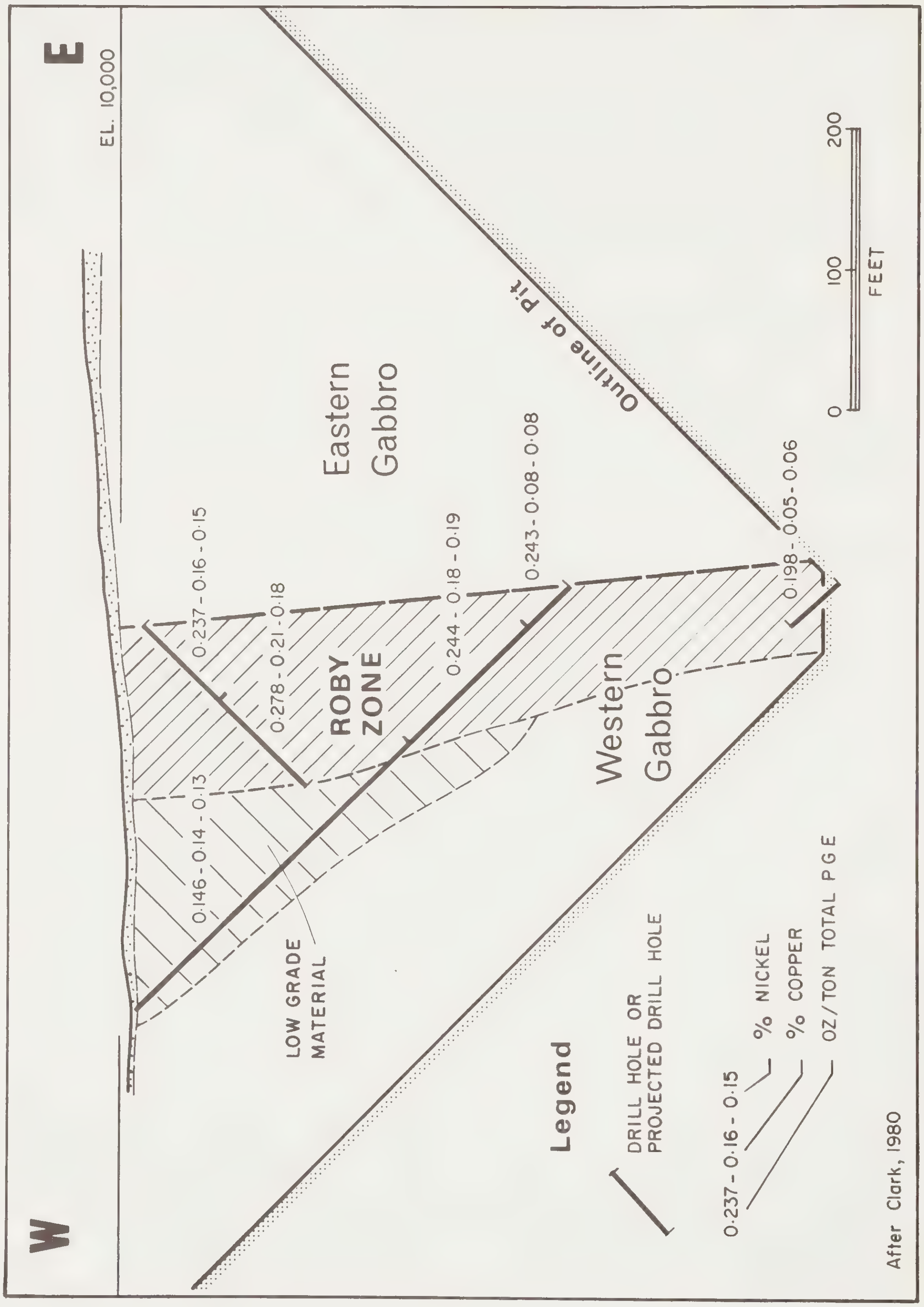
Mineralization

Of the several known zones of Cu-Ni and PGE mineralization, the Roby Zone is currently the most important and the C Zone the next most important.

The Roby Zone has received the most attention to date. It strikes N20W, dips steeply east, and has a strike length of about 600 m (Figure 5). The mineralization is contained within the so-called mixed zone between the Western Gabbro and the Eastern Gabbro. The eastern contact of the Roby Zone with the barren Eastern Gabbro is sharp. Up to several metres of altered pyroxenite containing sulphides and PGE values commonly is present at this contact. The mixed zone comprises Western Gabbro, sections of Eastern Gabbro and altered pyroxenite, and coarser gabbroic pegmatoid sections. Sulphides are sparsely disseminated throughout the mixed zone for widths up to about 100 m. Ni-Cu and PGE values gradually drop off westward.

In general, PGE content is related to total sulphide content. However, in detail, the relationship is more complex, since some areas with relatively low sulphide content have higher PGE values.

The deepest hole confirms that the Roby Zone extends to a depth of at least 375 m below surface.



Cross Section 514 – Lac des Iles

Figure 5

The C Zone is located just south of the Roby Zone and apparently trends east-west, where the Eastern Gabbro contact also turns to the east. The geological setting is the same as that of the Roby Zone, but PGE values do not seem to be as continuous within the zone. Some exploration potential appears to exist in this area.

Mineralogy

The mineralogy of the Cu-Ni and PGE mineralization at Lac des Iles has been studied by Cabri and Laflamme (1979) and Watkinson and Dunning (1979). There are two distinctive groups of metallic minerals: the copper, nickel and iron sulphides and the platinum group minerals (PGM).

The sulphides occur mostly as intercumulus blebs; however, stringers and veinlets of pyrite and chalcopyrite are common in altered and sheared rocks. Net-textured sulphides were noted occasionally.

The principal sulphide minerals are pentlandite, pyrite, chalcopyrite and pyrrhotite, in roughly equal proportions overall, but in variable proportions from sample to sample. In some samples, millerite was present, both with and without pentlandite. Other minerals present in minor or trace quantities include galena, magnetite, sphalerite, and siegenite-violarite: $(Co,Fe)(Ni,Fe)_2S_4)$.

The most common PGM's identified by the two studies are:

braggite series	$(Pd,Pt)S$
vysotskite	$(Pd,Ni)S$
kotulskite	$PdTe$
isomertieite	$Pd_{11}As_2Sb_2$
merenskyite	$PdTe_2$
sperrylite	$PtAs_2$
moncheite	$PtTe_2$

In both studies, braggite and vysotskite were the most abundant PGM's. They occur commonly with pentlandite. Significant palladium also appears to be present in pentlandite, averaging 0.19% in pentlandite grains analyzed by Cabri and Laflamme (1979).

Reserves

Various reserve figures have been quoted in company reports and in the press for the Lac des Iles PGE deposits, for example:

(a) 20.4 million tonnes @ 0.167 oz/ton PGE (Northern Miner Magazine, May 1986)
(b) 12,000 tons per vertical foot @ 0.185 oz/ton PGE, 0.22% Ni, 0.22% Cu, and 0.02 oz/ton Au in two zones, or 30,000 tons per vertical foot @ 0.14 oz/ton PGE in the two zones (Northern Miner, April 7, 1986)
(c) 6,490,000 tons open pit probable reserves @ 0.18 oz/ton PGE in the Roby zone, plus C zone open pit probable reserves of 900,000 tons @ 0.14 oz/ton PGE (The Sheridan Platinum Group Ltd. prospectus, December, 1980)

The reserves listed in (a) and (b) appear to be geological or in-situ reserves, whereas those listed as (c) are reported as open pit probable reserves. The open pit reserves have been estimated in the 1980 Clark report, to a depth of 500 ft. for the Roby zone and 200 ft. for the C zone. Mining dilution has not been applied.

Clark's open pit probable reserves appear to be conservative and are used in the present review. The Roby pit stripping ratio is 3.0 to 1. In addition to the 0.18 oz/ton PGE, the Roby zone is estimated to average 0.1% Cu, 0.1% Ni, and 0.01 oz/ton Au.

Not all of the Roby zone mineralization was included in

the open pit reserves. Clark states that the Roby zone pit, if extended deeper, could add approximately 1 million tons of mineralized material and 10 million tons of waste, slightly raising the grade, but increasing the overall stripping ratio to 3.9 to 1. The Roby zone is open at depth below about 600 ft., and it is our understanding that diamond drilling is currently being carried out to test for its depth extension.

Since all of the drill core was assayed for total PGE, the relative amounts of palladium and platinum are not known with certainty. According to the Clark report, some check assaying was carried out by Rustenberg Platinum in South Africa in 1975, confirming the original Bell-White Laboratory results, and showing Pd:Pt ratios of 8:1 or more.

Other information is available in the form of head assays for the mill flotation test work reported by Clark. Pd:Pt ratios for six selected tests range from 7.1 to 19.2, and give a ratio of 9.6 using the average Pd and Pt assays.

With the limited amount of data available, it appears that the Pd:Pt ratio is in the range of 8 to 10. Clearly, more assay work is required to determine the ratio with confidence.

Metallurgy

Clark reports that four laboratories have carried out a total of 21 flotation tests on Lac des Iles material. Using the six tests with the best results on samples of approximately reserve grade, he predicts the following recoveries and expected concentrate grades:

	Pd oz/ton	Pt oz/ton	Cu %	Ni %
Mill feed	0.153	0.017	0.10	0.10
Concentrate				
(4% of feed)	2.87	0.28	2.0	1.6
Recovery	75%	65%	80%	65%

Clark recommends further sampling, mineralogical examinations, and metallurgical testing; particularly to identify variations within the Roby zone and to optimize mill process and design. He suggests that a pilot plant test should possibly be carried out.

Economic Potential

The Clark report (1980) considered the possibility of the Lac des Iles Roby zone being developed as a small scale open pit mine and mill complex (about one million tons per annum). Mining would be done with leased equipment. The concentrate would be sold to Inco, which exports its PGE concentrates to Europe.

Key technical and economic parameters in 1980 for the Lac des Iles Roby deposit are summarized in Table 1.

Using 1980 mining costs, reserves and metal recoveries as per the previous sections, and purchase terms offered by Inco in 1978, Clark estimated that sufficient operating profit could be generated to give the project a significant, pre-tax, discounted present value. The subsequent collapse in palladium and platinum prices in 1981 caused the project to be shelved until early 1986, when price increases renewed interest in potential development.

Using Clark's basic parameters and updating such factors as operating costs and metal prices, RPA has carried out a brief, preliminary, order of magnitude assessment of the economic potential of the Lac des Iles Roby zone. For this order of magnitude assessment, Clark's technical data and basic assumptions are used without any independent checkwork. Prices for PGE, Cu and Ni are taken from the August 18, 1986 issue of The Northern Miner. Because of

TABLE 1

SUMMARY DATA SHEET - LAC DES ILES DEPOSIT

Property	Lac des Iles - Roby Zone
Owned by	The Platinum Group Ltd., under option to Madeleine Mines Ltd.
Data source	Glenn R. Clark Report, August 4, 1980
Reserves	6,490,000 tons open pit probable
Grades	0.179 oz/ton total PGE (Pt: Pd ratio typically greater than 1:8, assumed to be 1:9) 0.1% Cu, 0.1% Ni, 0.01 oz/ton Au
Type of Mining	Open Pit to 500 ft., stripping ratio 3:1
Type of Processing	Flotation with recoveries of 75% Pd, 65% Pt, 80% Cu, 65% Ni, 75% Au
Production Rate	1,000 to 3,000 tons per day
Capital costs	\$18 million at 1,000 tons per day \$30 million at 3,000 tons per day
Operating costs	\$22.72/ton at 1,000 tons per day \$18.14/ton at 3,000 tons per day
Economic Parameters	Mining by leased equipment; estimated cost of \$2.08/ton in 1980 dollars Milling \$5.20 to \$8.00/ton depending upon scope of operation Sales of concentrate to Sudbury smelters

Prices used ($US)

	1980	Aug. 1986
Pd	$225/oz	$125/oz
Pt	$420/oz	$535/oz
Ni	$3.50/lb	$1.80/lb
Cu	$0.92/lb	$0.58/lb
Au	$512/oz	$375/oz

NSR (1980)	Cdn. $35.35/ton before operating costs
Operating Profit	$12.49/ton @ 1,000 tpd, $15.78/ton @ 2,000 tpd, $17.21/ton @ 3,000 tpd

uncertainty of its average content in the deposit, gold is ignored.

Results of RPA's order of magnitude reassessment suggest that the Lac des Iles Roby Zone will currently generate about $12.00 Cdn less in net smelter return than it would have in 1980. This is principally due to lower palladium prices. Higher mining and processing costs than in 1980 are partly offset by a lower dollar exchange rate. It appears that a significantly increased reserve would be needed to justify a larger mining throughout than 3,000 tons per day and perhaps support a viable operation.

In the context of rising PGE prices and uncertainty about South Africa, further work and economic studies on the Lac des Iles property are justified; in particular:

- fill-in and exploration drilling
- upgrading of access road
- stripping and bulk sampling
- mineralogical studies and metallurgical testing
- investigation of potential electrical power sources
- updated pre-feasibility study

MARATHON

Property Location and Infrastructure

The Marathon Cu-PGE property was purchased from Anaconda Canada Explorations Ltd. in 1985 by Fleck Resources Ltd., a Vancouver-based junior mining company. Teck Corporation of Vancouver recently acquired an option to earn a 50% interest in the Marathon Property by bringing it into production.

The property is located about 10 km northeast of Marathon, Ontario. Marathon is a pulp mill town adjacent to Trans-Canada Highway 17 on the northeast shore of Lake

Superior some 250 km east of Thunder Bay. Access to the property is by gravel and dirt road from Highway 17.

The property is well located with respect to infrastructure, and is near the new gold mining camp at Hemlo, east of Marathon. The main CPR line passes through Marathon, and a major hydroelectric power transmission line passes about one km north of the deposit.

History

1920's to 1940's - prospecting and other work on titaniferous magnetite and disseminated chalcopyrite occurrences (Milne, 1967)

1963-66 - Anaconda Canada Explorations Ltd. carried out considerable work, including 171 diamond drill holes totalling some 119,000 ft. A large, open pittable Cu deposit with low PGE values was outlined.

1985 - Fleck Resources Ltd. purchased a 100% interest in the Marathon property from Anaconda and carried out re-assaying of core, trenching and diamond drilling (8,500 ft.).

1986 - Fleck Resources - metallurgical testing; Kilborn feasibility study in progress

1986 - Property optioned to Teck Corporation, which can earn a 50% interest by bringing it into production.

Geological Setting

The Marathon Cu-PGE deposit is on the eastern margin of the Coldwell complex, which is a circular alkaline intrusion some 25 km in diameter, located on the north shore of Lake Superior. The complex intrudes Archean supracrustal and granitoid rocks, and has an age of about 1,050 million years (Mitchell and Platt, 1982).

The Coldwell complex is a composite intrusion, consisting of at least three successions of ring dikes and cone sheets (Currie, 1980). Mitchell and Platt (1982) interpret three intrusive centres, which become younger from east to west. The oldest consists of a ring-shaped gabbro intruded by ferroaugite syenite. The middle intrusive centre comprises biotite gabbro and nepheline syenite. The youngest centre consists of syenites and quartz syenites.

The Marathon deposit is hosted by the eastern border gabbro of the first intrusive centre, the earliest phase of the Coldwell complex. On the property area, the oldest intrusive unit is a fine-grained, relatively uniform, gabbro. This fine-grained gabbro is intruded by a coarse-grained, heterogeneous gabbro, which was emplaced between the fine-grained gabbro to the west and hornfelsed metavolcanic country rock to the east. Contacts strike north-south and dip in the order of 30^{o} to the west.

The coarse-grained, heterogeneous gabbro hosts the Marathon Cu-PGE deposit and is characterized by the following features (Wilkinson, 1983; Watkinson et al, 1983):

- xenoliths of country rocks
- inclusions of fine-grained gabbro
- patches of hybrid gabbro, biotite gabbro and pegmatitic gabbro
- thin, irregular sheets of mottled gabbro
- zones of potash feldspar alteration
- pyroxene and olivine rich gabbro towards the base

The Marathon deposit does not readily fit into any of the defined PGE deposit classes; therefore, it has been given a new class, Alkaline-type.

<u>Mineralization</u>

The Marathon deposit consists of disseminated sulphides

within the coarse-grained, heterogeneous gabbro unit over a strike length of about one mile. As described above, this gabbro is part of the marginal phase of the Coldwell Complex. The sulphides consist of pyrrhotite, chalcopyrite, cubanite and pentlandite (Wilkinson, 1983).

Alteration is present in the immediate vicinity of sulphide grains, and consists of saussuritization of plagioclase, uralitization of clinopyroxene, serpentinization of olivine, and development of small mariolitic cavities containing calcite and quartz.

Mineralogy

Little work appears to have been done to define the platinum group mineralogy of the Marathon deposit. Wilkinson (1983) tentatively identified two PGM in his M.Sc. thesis work:

hollingsworthite	(Rh,Pt,Ir)AsS
merenskyite	$Pd(Te,Bi)_2$

More mineralogical study of the PGM is required.

Reserves

The Marathon property contains a large, relatively low grade, Cu-PGE deposit. In its 1985 Annual Report, dated June 1985, Fleck stated drill indicated reserves, based on the previous Anaconda work, to be 34.4 million tons at 0.47% Cu and 0.039 oz/ton Pt/Pd, in addition to Ni, Co, Au and Ag values.

Subsequent to its 1985 program of re-assaying (by Acme Labs in Vancouver), trenching and diamond drilling, Fleck reported drill indicated reserves in early 1986 to be 46.9 million tons grading 0.42% Cu, 0.02 oz/ton Pt, 0.054 oz/ton Pd, with additional values of Ni, Co, Rh, Au and Ag. Since

that time, more re-assaying has been done by Inco and Bondar-Clegg. It is our understanding that the Inco PGE grades are between the early Anaconda results and the Acme Labs assays.

It is our understanding that the Inco results were used to derive the average grades used in the preliminary Kilborn study, completed in April 1986. These reserve figures are reported to be:

46.9 million tons to a depth of 600 ft.

Cu	0.46%
Ni	0.04%
Pt	0.012 oz/ton
Pd	0.044 oz/ton
Ag	0.110 oz/ton
Au	0.006 oz/ton
Rh	0.005 oz/ton

Metallurgy

Fleck has published some results of tests on four bulk samples totalling 400 lb. from the Marathon deposit. These were reported as preliminary results from pilot plant tests by Lakefield Research. One set of results with head grades similar to the reported reserve grades is as follows (press release dated February 19, 1986):

Metal	Head Assay	Recovery	Concentrate Grade
Copper	0.44%	88.62%	21.00%
Nickel	0.034%	48.33%	0.89%
Platinum	0.011 oz/ton	78.57%	0.452 oz/ton
Palladium	0.052 oz/ton	82.36%	2.450 oz/ton
Silver	0.160 oz/ton	60.00%	2.790 oz/ton
Gold	0.031 oz/ton	65.56%	0.235 oz/ton
Cobalt	0.010%	-	0.28% (est.)
Rhodium	-	-	0.023 oz/ton

Our information suggests that these recovery figures were used in the preliminary Kilborn study.

Economic Potential

The Kilborn preliminary study, termed a pre-feasibility review, was completed in April 1986, at which time Fleck announced that a feasibility study would be carried out by Kilborn Engineering of Toronto, and that the preliminary study indicated a return on capital investment of approximately 20%.

Kilborn's preliminary study estimated capital costs of about $127.3 million for a 12,500 ton per day mine/mill complex with a ten-year mine life. Mining would be by open pit with a 2:1 stripping ratio. Key economic parameters are listed in Table 2. Reserves and metallurgical recoveries are as listed in previous sections. Concentrates would be sold to Inco.

On the basis of the Kilborn preliminary study, the Marathon project clearly warrants more work. Fleck is carrying out detailed sampling and fill-in diamond drilling to firm up geological interpretation and reserves, and has commissioned Kilborn to carry out a feasibility study. In conjunction with this study, more work, such as metallurgical testing, should be carried out.

CRYSTAL LAKE

Property Location and Infrastructure

The Crystal Lake property is held by Great Lakes Nickel Limited, which is effectively controlled by Boliden AB. The property is located 50 km south of Thunder Bay, a major

TABLE 2

SUMMARY DATA SHEET - MARATHON DEPOSIT

Property	Marathon
Owned by	Fleck Resources Inc.
Data source	Kilborn Pre-feasibility Review, April 1986 (confidential)
Reserves	46.9 million tons to 600 ft. depth
Grades	0.46% Cu; 0.04% Ni; 0.044 oz/ton Pd; 0.012 oz/ton Pt; 0.110 oz/ton Ag; 0.006 oz/ton Au; 0.005 oz/ton Rh
Type of Mining	Open Pit, stripping ratio 2:1 (?)
Type of Processing	Flotation to produce a sulphide concentrate
Production rate	12,500 tons/day with 10-year life
Capital costs	$127.3 million for mine/mill complex
Operating costs	Mining and milling $8.05/ton
Net smelter return	Concentrate sales to Inco $16.00/ton
Cash flow	$135 million per annum
Payback period	4.07 years
Rate of return	19.04% on capital investment

transportation and population centre in northwestern Ontario. The property is readily accessible on a gravel road from Highway 597, and is only a few km from Highway 61 which joins Thunder Bay and Duluth, Minnesota.

History

1952 - trenching by Falconbridge Nickel

1954 - drilling (6 holes for 3,471 ft.) by Barker and Dawidowich intersected Cu-Ni zone.

- drilling by Mogul Mining Corp. Ltd. (7 holes for 5,556 ft.) tested Cu-Ni zone.

1964-67 - considerable drilling, underground exploration, and metallurgical testing by Great Lakes Nickel Corporation Limited.

1969 - Great Lakes Nickel Limited formed by merger of Great Lakes Nickel Corporation Limited and Thunder Bay Nickel Mining Corporation Limited, the latter having held the east end of the Crystal Lake deposit.

1970 - publication of Ont. Dept. of Mines Geological Report 87 by J.J.C. Geul with detailed map.

In 1972, Great Lakes Nickel entered into a financing agreement with Boliden AB of Sweden. Boliden carried out considerable work, including ore treatment studies, considerable diamond drilling, some underground and surface development, bulk sampling and pilot plant testing, culminating in a feasibility study in 1974. A total of 192,550 ft. of surface diamond drilling and 85,899 ft. of underground diamond drilling has been carried out on the Crystal Lake property, in addition to driving of a 3,417 ft. long adit.

Due to increasing interest rates and escalation in projected costs, Boliden placed the property on a standby basis in 1975. Economic reviews have since been carried out every few years, each time resulting in the property remaining on standby status.

In 1985, Great Lakes Nickel carried out some preliminary studies on drill core samples which confirmed the presence of minor amounts of PGE within narrow bands above the delineated sulphide zone.

As of January 1, 1986, Great Lakes Nickel and Boliden entered into an agreement to terminate their 1972 financing agreement. Boliden still holds a 29% interest in Great Lakes Nickel.

In August 1986, Great Lakes Nickel and Fleck Resources Inc. signed a letter of intent for Fleck to carry out work on the Crystal Lake property.

Geological Setting

The general area is underlain by the Proterozoic Rove Formation, which consists of greywacke, argillite, shale and black pyritic shale. The recessive-weathering Rove Formation is intruded by Proterozoic (Keweenawan) mafic sills and dikes of different ages which stand up as resistant ridges and mesas.

The oldest mafic intrusions are the Logan diabase sills (1.4 billion years), followed by the Pidgeon River olivine diabase dikes and sills. The Crystal Lake Gabbro, which hosts the Great Lakes Nickel deposit, is considered to be equivalent to the Duluth Gabbro, dated at 1.1 billion years (Geul, 1970).

The Crystal Lake Gabbro outcrops as a Y-shaped body about 5 km long, trending east-west. The north and south arms

converge to the east. The Great Lakes Nickel deposit is in the lower part of the north arm. The intrusion here is in the form of a trough about 1,500 to 2,000 ft. wide, open to the west. The keel of the trough plunges east at 15 to 20 degrees from its surface outcrop. The gabbro is at least 2,000 ft. thick at its east end.

Geul (1970) and Whittaker (1986) divide the Crystal Lake Gabbro into three zones:

- Upper zone - medium grained massive gabbro to olivine gabbro.
- Middle zone - layered anorthositic gabbro with gabbro and pegmatitic olivine gabbro patches; host for the Cu-Ni-PGE deposit.
- Basal zone - 1-6 m thick, very fine grained to aphanitic gabbro in contact with Rove Formation shales, and containing hornfelsed angular fragments of shales and wackes.

The Crystal Lake deposit is classified as Noril'sk-type, along with the Duluth Gabbro deposits.

Mineralization and Mineralogy

The Crystal Lake Cu-Ni-PGE deposit is within the Middle zone of the Crystal Lake Gabbro. The deposit consists of chalcopyrite, pyrrhotite, and pentlandite disseminated in anorthositic and olivine gabbro layers, and in the pegmatitic gabbro and olivine gabbro patches. Sulphide mineralization is often associated with pegmatitic patches. The sulphides occur as fine grained disseminations to near-massive blebs.

Little published information is available on the dimensions of the deposit, however, it is in the order of 300 m or more wide, 3,000 m or more in length, and averages perhaps 25 to 30 m in thickness (Geul, 1970).

In addition to the sulphides, fine grained chromite is sparsely disseminated throughout much of the Middle zone of the Crystal Lake Gabbro north limb. The chromite extends higher up in the gabbro than the sulphide zone. In addition to the disseminated chromite, there is a distinct, but thin, chromitiferous layer at the top of the Middle zone and a discontinuous layer apparently within the Upper zone.

No information is available on the PGE mineralogy of the Crystal Lake deposit.

Reserves

Great Lakes Nickel reports proven and indicated reserves for the Crystal Lake deposit to be:

45.6 million tons averaging 0.344% Cu and 0.183% Ni, plus minor precious content.

This is based on a 1976 update of the 1974 Boliden feasibility study. Precious metals include palladium, platinum, rhodium, gold and silver. Great Lakes Nickel has not published grades for the precious metals, but information available from 1970 studies suggests that the grades are in the order of:

0.02 oz/ton Pd
0.006 oz/ton Pt
0.0004 oz/ton Rh
0.002 oz/ton Au
0.06 oz/ton Ag

Economic Potential

Data on the Crystal Lake deposit are summarized in Table 3, based mostly on published information from Boliden's 1974

TABLE 3

SUMMARY DATA SHEET - CRYSTAL LAKE DEPOSIT

Property	Crystal Lake	
Owned by	Great Lakes Nickel Limited, under option to Fleck Resources Inc.	
Data Source	Great Lakes Nickel Annual Reports Northern Miner Press clippings	
Reserves	45.6 million tons proven and indicated	
Grades	0.344% Cu	0.183% Ni
	In the order of:	
	0.02 oz/ton Pd	0.002 oz/ton Au
	0.006 oz/ton Pt	0.06 oz/ton Ag
	0.0004 oz/ton Rh	
Type of Mining	Underground mining 2.5 million tons per year	
Type of Processing	Autogenous grinding; two separate floation circuits for Cu and Ni	
Production Rate	Mining 2.5 million tons per year to produce 40,000 tons of Ni concentrate and 31,250 tons of Cu concentrate	
Capital Costs	$100 million plus	
Economic Parameters	This property has been previously regarded as a Cu-Ni project and appears to be uneconomic at current prices. The current interest in PGE, formerly a minor consideration, has created a climate for re-evaluation, which is currently underway.	

feasibility study. At that time, capital costs were estimated at about $40 million for a mine-mill complex to mine 2.5 million tons per year and produce separate copper and nickel concentrates.

In the 1977 Annual Report, Great Lakes Nickel reported that the capital costs and operating costs were estimated to be significantly higher than in the 1974 feasibility study. At the present time, capital costs would likely be well in excess of $100 million.

As noted in recent Great Lakes Nickel annual reports, copper and nickel prices will not allow for economic development of the low grade Crystal Lake deposit. However, renewed interest in PGE makes the property worth reviewing from an exploration point of view. Of interest is the reported presence of minor PGE values within narrow bands above the previously delineated sulphide zone. Further work should focus on these relatively unexplored bands as well as on areas within the deposit where PGE values may be enriched.

OTHER PROSPECTS AND SHOWINGS IN ONTARIO

Ontario has received the bulk of PGE exploration attention during the past two years, largely stemming from the existence of PGE (Ni-Cu) deposits sufficiently attractive to be the subject of feasibility studies and pre-production preparations. Virtually all the PGE production in Canada during the last 40 years has come from Ontario deposits, almost exclusively as by-products from Ni-Cu mining, especially the Sudbury deposits. Several other Ni-Cu deposits with minor PGE and Au credits have been mined in the past in Ontario, and some Ni-Cu (PGE) deposits contain significant reserves which are clearly subeconomic, or where mining has been temporarily suspended due to present low base metal prices. An example is Inco's Shebandowan operations west of Thunder Bay.

These (semi) massive Ni-Cu sulphide deposits have received intensive and extensive exploration emphasis in the past but the present exploration focus has turned to PGE-rich deposits (note however that Noril'sk deposits and Ungava deposits are both Cu-Ni rich and PGE-rich). The present understanding on genesis of PGE-rich deposits has led to the realization that the potential for PGE-rich deposits has been only nominally tested.

In this section, properties presently being explored and which contain reported PGE values are emphasized. All properties are at the exploration stage. Ni-Cu dominant massive sulphide deposits are merely listed as examples in the "General Classification of PGE Deposits" for reasons stated in the preceding paragraph.

Big Trout Lake

The Big Trout Lake ultramafic/mafic intrusion is located in northwestern Ontario about 400 km northeast of Red Lake and 300 km north of Pickle Lake. Infrastructure is nonexistent, and access is by float-equipped aircraft.

The Big Trout Lake layered intrusion consists of a lower peridotite part and an upper anorthositic part (Hudec, 1964; Thurston et al, 1979; Borthwick and Naldrett, 1984, 1986; Whittaker, 1986). Chromite occurs in both disseminated and layered form in serpentinized peridotite, where it defines layering in the peridotite. Disseminated sulphides (chalcopyrite) are associated with chromite in the serpentinite.

Whittaker (1986) suggests that the layering and chemistry of the Big Trout Lake intrusion are similar to other large layered intrusions such as the Muskox and Bushveld complexes.

The Big Trout Lake intrusion has been explored for

Cu-Ni-PGE in the past by Inco and by Canadian Occidental Petroleum. The ultramafic portion has recently been acquired by International Platinum Corporation (formerly Silver Lake Resources Inc.). In late 1985, drilling outlined a 160-ft. wide zone of anomalous PGE values separate from the known chromite horizons (Silver Lake 1985 Annual Report). More work is planned for 1986.

The Big Trout Lake mineralization is tentatively classified as Merensky-type, or possibly Pechanga-type.

Puddy Lake/Chrome Lake

International Platinum Corporation has staked the small mafic and ultramafic bodies located west of Lake Nipigon some 200 km north of Thunder Bay. The intrusives consist of a body of serpentinized ultramafic and a poorly layered gabbro body intruded into Archean paragneiss, sediments and volcanics (Bullock, 1986; Whittaker, 1986). The Puddy Lake/Chrome Lake intrusives are interpreted to be Alpine type (Whittaker, 1986).

Mineralization in serpentinized ultramafics comprises disseminated and layered chromite, and narrow Cu-Ni veins containing up to 1% Ni, 0.5% Cu, 283 ppb Pt and 559 ppb Pd. Gabbro contains up to 0.25% Ni, 0.2% Cu, and 128 ppb Pt/Pd.

No further exploration is believed to be planned for 1986, pending evaluation of field data.

Reaume Township

Imperial Platinum Corporation holds a property north of Timmins which contain a platinum showing with values up to 0.06 oz/ton Pt (Northern Miner, July 7, 1986).

Quetico Fault - Lac des Iles Area

Numerous small mafic/ultramafic intrusions in this general area of northwestern Ontario are unofficially reported to contain interesting PGE values and low Ni-Cu values based on recent grassroots exploration work. Several of these intrusive bodies are distributed in a 20-25 km diameter ring with the Lac des Iles complex on its eastern margin. Others have been identified as the Tib Lake, Dog River, Taman Lake, Demars lake and Legris Lake intrusions (Sutcliffe, 1986, field trip map).

Other mineralized mafic/ultramafic intrusions are reportedly strung out along the Quetico fault which itself is tangential along the southern margin of the previously mentioned ring structure. It seems that the mafic/ultramafic intrusions in this region comprise a petrologic province wherein the intrusions may be genetically related.

Coldwell Complex

A PGE showing was discovered by local prospectors in 1986 in the central part of the Coldwell Complex near Marathon. Chalcopyrite, magnetite, chalcocite and pyrite mineralization with significant values in Pd, Pt, Au, and Ag has been reported over a strike length of 2,500 ft.

OTHER NORTH AMERICAN PGE DEPOSITS

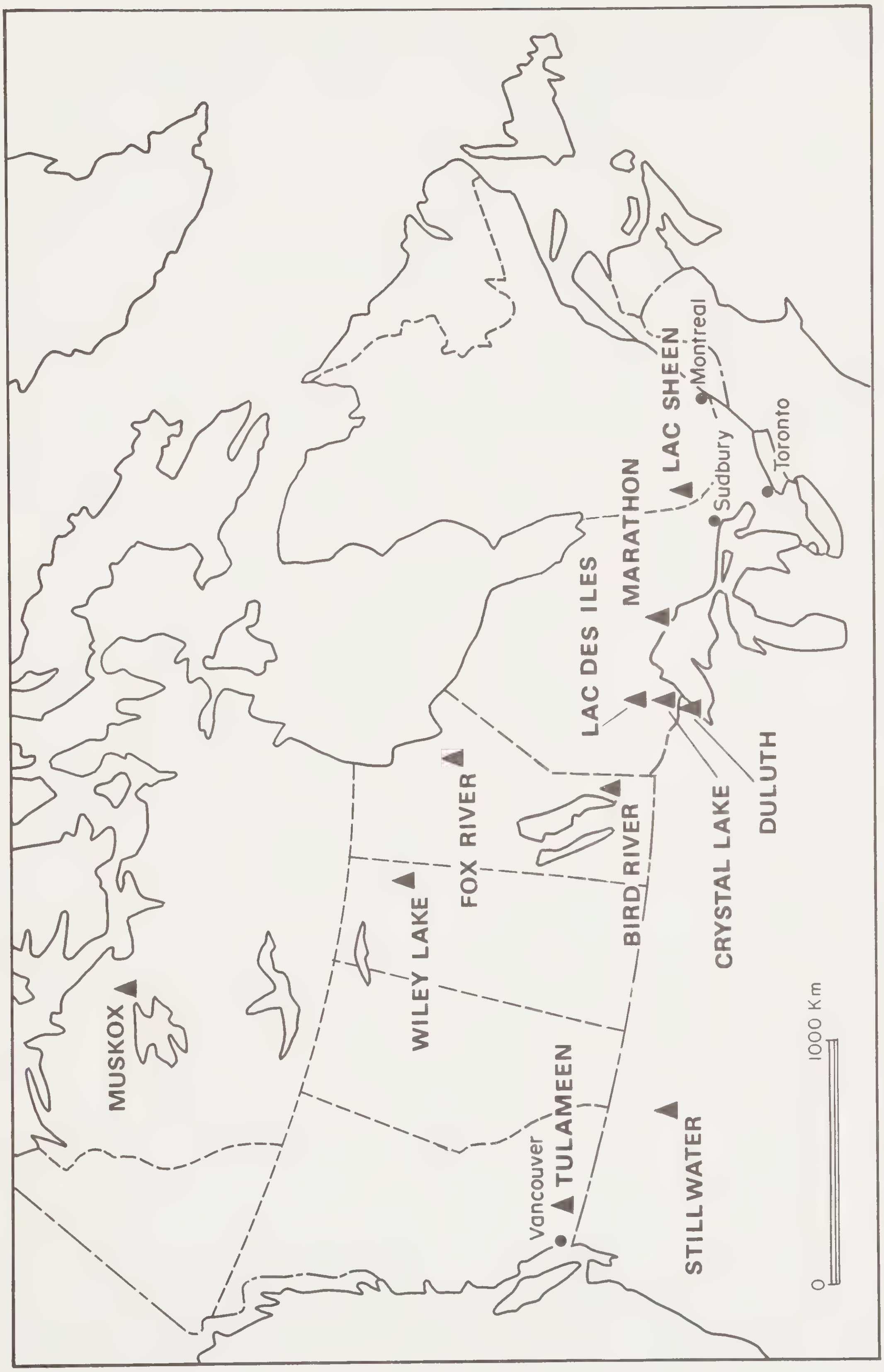
Outside of Ontario, PGE deposits, prospects and showings exist in Quebec, Manitoba, Saskatchewan, British Columbia, Alaska, Montana, and Minnesota (Figure 6). Of these, only the Stillwater Complex in Montana, the Duluth Complex, in Minnesota, and the Ungava Nickel Belt in northern Quebec appear to have deposits which are deemed to be imminent or potential producers. These are so deemed because they are at advanced stages of exploration and because there exists a substantial amount of hard data, mostly not yet publicly available. Other PGE prospects and showings outside of Ontario are only briefly described below because they are at earlier stages of exploration and little data are available, or they are of exceptionally low grade or very small size.

IMMINENT AND POTENTIAL PRODUCERS OUTSIDE OF ONTARIO

Stillwater Complex, Montana

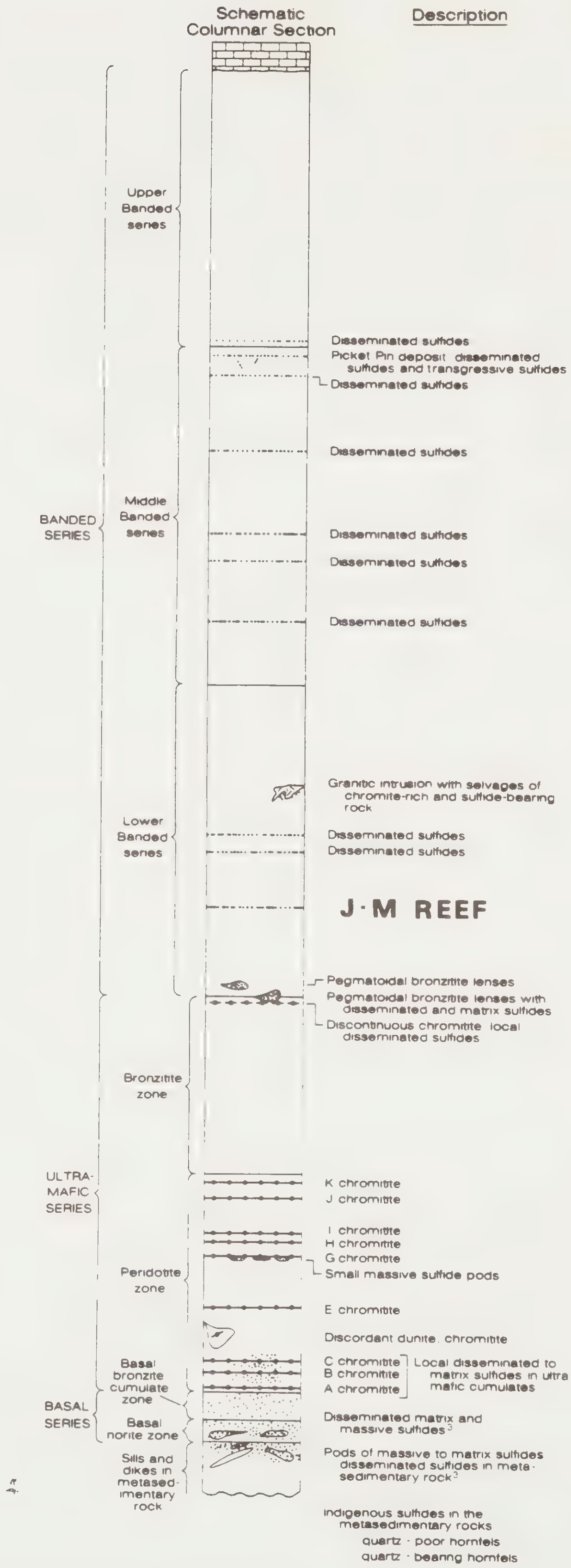
The Stillwater Complex contains important resources of PGE, chromite, and Ni-Cu in separate deposits at different stratigraphic levels (Figure 7). Nominal amounts of chromite were exploited during and after World War II. Production of PGE from the J-M Reef is expected to start in 1987 by the Stillwater Mining Co., a consortium comprising Chevron Corp. (the operator), Manville Products Co. and Lac Minerals Ltd.

The Stillwater Complex is a 2.71 billion year old mafic to ultramafic sill-like intrusion with a moderate dip. Its minimum dimensions are 48 km x 7.4 km. It is terminated at both ends by faults and bounded by an unconformity and younger sedimentary rocks in its upper (northern) exposed section. The original dimensions of this intrusion were likely much larger.



Other North American PGE Occurrences

Figure 6



Stillwater Stratigraphic Section

After: Page et al. 1985

Figure 7

The stratigraphic section (Figure 7) shows the main zones which are termed the Basal, Ultramafic, and Banded Zones. The H.P. Reef is located in the Lower Member of the Banded Zone. Of ancillary PGE interest is the "A" chromitite (average 3.1 g/t total PGE) in the Peridotite Member of the Ultramafic Zone. The "A" chromitite is somewhat equivalent to the UG2 layer in the Bushveld Complex.

The H.P. Reef is a virtually continuous zone 39 km long and about 2 metres thick. It contains very high PGE values accompanying disseminated pyrrhotite, chalcopyrite, and pentlandite. Total sulphides commonly range from 0.5 to 1.5% by volume in the mineralized zone.

The H.P. Reef and the Merensky Reef show striking similarities (cumulate plagioclase, disseminated sulphides, pegmatite, biotite, graphite, potholes), and the H.P. Reef is classified as Merensky-type. The H.P. Reef and J-M Reef are the same although this report uses H.P. Reef for the broader extent of the zone, whereas the J-M Reef is used for the same zone on a property scale.

The main sulphide minerals in the J-M Reef are pyrrhotite, chalcopyrite, and pentlandite, and the major platinum group minerals are braggite (Pt,Pd)S, vysotskite PdS, moncheite $PtTe_2$, and Pt-Fe alloys (Naldrett 1981). Significant amounts of PGE have been recognized in pentlandite.

The J-M Reef has been explored in detail in two segments (Naldrett, 1981). Segment one is 6.57 km long, 2 m thick and grades 11.4 g/t Pd, 3.3 g/t Pt, and 0.15% Cu + Ni. Segment two is 5.5 km long, 2 m thick, and grades 17.3 g/t Pd and 5 g/t Pt. The U.S. Bureau of Mines has analyzed "typical Stillwater material" and reports values of 0.509 oz/ton Pd and 0.130 oz/ton Pt (U.S.B.M. Min. Facts and Problems, 1985).

Reserves are quoted to be 35 million ounces total PGE (Buchanan, 1979, from Johnson Matthey, 1986). PGE resources in the Stillwater are 225 million ounces, about 75% of total USA resources. The Pt:Pd ratio is about 1:3.5, making the J-M Reef much richer in Pd, but the grades are so high that a ton of J-M ore contains on average about the same amount of Pt and four times the amount of Pd as a ton of Merensky Reef ore.

The J-M Reef is the most advanced and unquestionably the most attractive potential producer of PGE in North America, and planned production by Stillwater Mining Company will provide globally minor but important amounts of Pt and Pd.

Production beginning in mid-1987 is scheduled for 500 tons per day, to produce 25,000 oz Pt and 75,000 oz Pd per year, doubling in 1991 to 50,000 oz Pt and 150,000 oz Pd per year (Johnson Matthey, 1985). Table 4 summarizes technical and financial data for the planned Stillwater operations. The J-M Reef is an attractive situation for mining by virtue of its thickness (2 m vs. 1 m for Merensky Reef) and high grade (14-22 ppm vs. 4-12 ppm for Merensky Reef), although block faulting has broken the J-M Reef into disjointed segments contributing to high mining costs. Jolly (1978) predicted that the J-M Reef will ultimately supply the Pd needs and one-quarter of the Pt needs of the U.S. Based on current mining plans, however, this seems unlikely in the foreseeable future.

Duluth Complex, Minnesota

Cu-Ni-PGE sulphide deposits in the Duluth Complex are very large and constitute considerable resources for each of the contained metals. The nickel resources alone represent the largest amount of nickel in one camp in the United States. PGE resources in the camp are estimated to be 50

TABLE 4

SUMMARY DATA SHEET - STILLWATER MONTANA

Property	Stillwater Mining Co.
Owned by	Chevron Corp. (operator) Lac Minerals Ltd. Manville Products Co.
Data source	N.A. Gold Mining Industry News Lac Minerals 1986 Annual Report
Reserves and Grades	400,000 tons proven @ 0.79 oz/ton PGE 1,600,000 tons possible @ 0.93 oz/ton PGE Pt: Pd Ratio 1:3
Type of Mining	Underground mining by horizontal tunnelling
Type of Processing	Flotation
Production Rate	500 tpd to 1990 1,000 tpd from 1991 Output targets at 500 tpd: 26,000 oz/year Pt: 78,000 oz/year Pd Output targets at 1,000 tpd: 50,000 oz/year Pt: 150,000 oz/year Pd
Capital costs	Phase 1 500 tpd US $17 million Phase 2 1000 tpd US $23 million Total US $40 million
Economic Parameters	Production scheduled for mid-1987. Regarded as a high grade, low reserve deposit. Major permits are in place for development. Manville has been given court approval to invest its share of capital costs.

million ounces (Jolly, 1978). However, the deposits are generally too low grade to be mined presently, and along with environmental concerns, the Duluth deposits remain questionable entities for mining in the immediate future.

The Duluth Complex is a large mafic intrusive mass extending from Duluth, Minnesota, to the Ontario border as an arcuate body 250 km along the northwest shore of Lake Superior. The intrusives are coeval with 1.12 billion year old Keweenawan basalts, which appear to have been fed by separate intrusive bodies in the Duluth Complex.

The Duluth Complex intruded Archean granitic rocks and volcanics, and Proterozoic Biwabik iron formation and Virginia slates and sulphide iron formation. The contact between the basement rocks and intrusives is well exposed along the northern and northwestern margins of the Complex, and generally dips southerly at 25 degrees.

The Duluth Complex occurs at the northern extremity of the Midcontinent Gravity High (intracontinental rift), near the apex of the southwesterly rift arm and the southerly rift arm. A third arm extends northerly from the north shore of Lake Superior into the Lake Nipigon area, and includes the Lac des Iles area. These rift or graben structures tend to be loci for deep-seated magma activity, and a similar three armed rift system ("Y" shaped, aulocagene) has been emphasized in the Noril'sk region.

The Duluth Complex has been divided into two main phases, the lower Troctolitic Series and the upper Anorthositic Series. Both Series are composed of multiple intrusions, some of which may have served as feeders to the Keweenawan basalts. Mineralization occurs along the western margin, mainly in the lower 300 m or at the basal contact of the Troctolite Series, and is associated with the South Kawishiwi, Partridge River, and Waterhen intrusive bodies. Mineralization occurs dominantly with disseminated sulphide

zones averaging 2% total sulphides, but massive and semi-massive sulphide zones may occur as the basal contact is approached. Sulphide mineralization locally penetrates the basement rocks.

Research studies have demonstrated that the basal part of the Troctolite Series has been strongly contaminated by the Virginia Formation, showing increasing Si, K, Na, Fe, S, Cu/Ni ratio, Fe/Ni ratio as the contact is approached (Tyson & Chong, 1984). Contaminants may have been added to the magma by hydrous, sulphur bearing fluids originating in the Virginia Formation (Tyson & Chong, 1984), and by assimilation of numerous Virginia Formation inclusions (Rao & Ripley, 1983). Strong presence of biotite in the lower 300 m of the Troctolite Series, and the intimate textural association of biotite with sulphides attests to the powerful role that country rock contamination has played in the mineralization process. Sulphur isotope studies indicate that greater than 75% of sulphur in the mineralized bodies has been derived from the country rocks (Naldrett, 1981b). Up to 10% graphite has been noted sporadically with mineralization (Naldrett, 1981b). Hollister (1980) described graphite to be restricted to the lower 300 m of the troctolite and explains that the carbon may have been fumed out of the Virginia Formation by the crystallizing troctolitic magma.

The mineralogy of the Duluth deposits, in general terms, comprises: major minerals pyrrhotite, chalcopyrite, cubanite, and pentlandite; minor minerals violarite, mackinawite, pyrite, sphalerite, and bornite; trace mineral talnakhite has been identified.

Numerous Cu-Ni deposits have been found by several mining companies along the western margin of the Duluth Complex. The main deposits listed without regard to size or economic viability, from north to south are the Inco Spruce deposit, the Inco/Hanna/Duval block, Newmont/Bear Creek Dunka Pit deposits, Amax Minnamax deposit, and U.S. Steel Dunka Road

deposit. Very little public information exists on the specific deposits, and the following data on the Spruce and Minnamax deposits is based on a resource study of the basal portion of the Duluth Complex, by the Minnesota Department of Natural Resources (Report 93, 1977).

In 1975, Inco submitted a proposal for an open pit mining operation on the Spruce Property with a 20 year life based on mineable reserves of 273 million tons grading 0.46% Cu, 0.17% Ni. This proposal was subsequently withdrawn. The Minnesota Department of Natural Resources (M.D.N.R.) estimated open pit and underground reserves for the entire Spruce property to be 700 million tons, using a cut-off grade of 0.5% Cu. A 10,000 ton bulk sample was taken by Inco for metallurgical tests. Inco reported (by-product) recoverable grades of 0.0262 oz Ag, 0.00075 oz Au, 0.00107 oz Pt, 0.00304 oz/ton Pd, 0.14% Co. Total Pt and Pd content is approximately 0.1 g/t. A 120 ton bulk sample, split from Inco's bulk sample, was metallurgically tested by the U.S. Bureau of Mines and produced a flotation concentrate containing 0.021-0.036 oz/ton Pt, 0.120-0.128 oz/ton Pd, 0.002-0.003 oz/ton Rh, 0.001-0.002 oz/ton Ir, and 0.001-0.004 oz/ton Ru (Sutton, 1982).

Amax estimated underground reserves of their Minnamax deposits to be between 330-375 million tons grading 0.8% Cu and 0.2% Ni, using a cut-off grade of 0.6% Cu. A high grade semi-massive sulphide zone grading 3% Cu and 0.6% Ni has also been identified. The M.D.N.R. estimated reserves for the Minnamax area to be 800 million tons, using a cut-off grade of 0.5% Cu.

The overall tonnage of disseminated Cu-Ni mineralization of the Duluth Complex is estimated by the M.D.N.R. to be 4.4 billion tons grading 0.66% Cu and 0.20% Ni, using a cut-off grade of 0.5% Cu and minimum thickness of 50 feet. PGE resources in the Duluth Complex using the Pt and Pd values in Inco's bulk sample amounts to 18 million troy ounces Pt + Pd.

PROSPECTS AND SHOWINGS OUTSIDE OF ONTARIO

Properties mentioned in this section are restricted to those receiving present exploration activity and those which have reported PGE values. Some properties contain old PGE occurrences which are receiving reactivated interest, and others contain new occurrences discovered by companies which have responded aggressively to the growing emphasis on PGE. Other platinum occurrences in North America are not described in this report since the number of occurrences in 10 provinces and 22 states (Fagen, 1986) goes beyond the scope of this report. Presumably, the best prospects and showings are receiving the bulk of exploration attention at this early stage. Locations of most of the prospects are shown in Figure 6.

Lac Sheen, Quebec

International Platinum Corporation, formerly Silver Lake Resources Inc., can earn a 50 percent interest in this property located about 12 km southwest of the village of Belleterre, Quebec. Cu-Ni-PGE float found in 1959 contained PGE values up to 0.60 oz/ton Pt/Pd (Bullock, 1986, Silver Lake Annual Report 1985). About 30 drill holes were completed by previous companies, with the best hole containing 0.326 oz/ton Pt/Pd over 5 feet. Pt:Pd ratio is 1.2:1, exceptionally high for North American deposits.

Drilling and trenching by Silver Lake in 1986 have confirmed earlier results and demonstrated continuity of the mineralized zone (e.g. 1 foot grading 0.18 oz/ton Pt/Pd), and the current drilling program is intended to test the presumed high grade zone and the down dip continuity of the deposit.

Geologically, the zone consists of disseminated chalcopyrite, pyrrhotite, and pyrite in an amphibolitized pyroxenite sill in Archean gneisses. "Green pegmatite" is intimately associated with the mineralized zone.

Fox River, Manitoba

BP-Selco can earn 60% interest from International Platinum Corporation (formerly Silver Lake Resources) in this joint venture property, located about 60 km southeast of Gillam, northern Manitoba (Bullock, 1986, Silver Lake Annual Report, 1985).

The Fox River Sill is a cyclically layered mafic/ultramafic intrusion at least 150 km in length and about 1.5 km average width. It intrudes lower Proterozoic volcanic and sedimentary rocks along the Thompson Belt trend. Previous exploration by Inco focussed primarily on Ni-Cu massive sulphides. Similarities with the Stillwater and Bushveld complexes, combined with encouraging but modest platinum/palladium values obtained in 1986, give this property good exploration potential. The geologic framework for the present program was established by Jon Scoates of the Geological Survey of Canada, who publicly reported a Pt/Pd value of about 1300 ppb and identified chromitite layers in the Fox River sill.

The sill is divided into lower ultramafic and upper mafic sequences, with the main PGE focus on the lower part of the mafic sequence, following the pattern established by the Bushveld Merensky Reef and Stillwater H.P. Reef. Four zones of disseminated magmatic sulphides have been recognized in the cyclically layered units of the mafic sequence. The initial drill program by BP-Selco in early 1986 identified two stratiform platiniferous zones and a third "disrupted" area of Pt/Pd mineralization. Reported values from the initial 5 hole drill program (Northern Miner, July 7, 1986) are:

30 feet averaging 0.007 oz/ton Pt/Pd
26 feet averaging 0.014 oz/ton Pt/Pd
62 feet averaging 0.008 oz/ton Pt/Pd
33 feet averaging 0.03 oz/ton Pt/Pd.

The initial BP-Selco drill program was deemed to be sufficiently encouraging to justify a second drill program in late 1986. The exploration situation remains wide open with other unattested zones of disseminated sulphides, and the full strata extent of the sill remaining to be tested. The possibility that the Fox River Sill may represent coalesced sills from multiple centres should be seriously considered.

Bird River, Manitoba

The Bird River Sill is a differentiated ultramafic/mafic synvolcanic body intruded into Archean volcanics of the Rice Lake Group. It is located about 150 km northeast of Winnipeg. The sill is about 25 km long and 700 m thick, and is divided into a basal sulphide unit, an ultramafic zone, and an upper gabbro zone. The sill is known primarily for its potentially economic chromite resources, which occur in the ultramafic zone.

Primary magmatic sulphides comprising pyrrhotite, pentlandite, chalcopyrite, and pyrite occur in the basal sulphide unit. PGE comprising Ru, Os, and Ir occur in chromite as inclusions of laurite $(RuOsIr)S_2$, and rutheniridosmine (Os, Ir, Ru alloy), with nearly total exclusion of Pt, Pd and Rh from chromite layers. The Geological Survey of Canada reports values of 480 ppb Pt and 1,800 ppb Pd from a sulphide bearing peridotite layer below a chromitiferous layer (GSC Paper 86-6). The presence of Pt and Pd in the basal sulphide unit and in the upper gabbro zone is being evaluated by exploration interests.

Falcon Lake, Manitoba

The Falcon Lake stock is a concentrically zoned intrusion located along the Trans Canada Highway 6 km west of the Manitoba-Ontario boundary. The stock is Archean age and intrudes Archean volcanics, but does not appear to be coeval with the volcanics (Gibbins, 1971). Zonation comprises a quartz monzonite core, granodiorite shell, and gabbro outer zone.

Gold mineralization with trace to 0.10 oz/ton Pt was identified by work in the early 1900's, and occurs on the Sunbeam, Waverley, and Gold Coin properties. Recent activity on these properties by Homestake Explorations and by Whiteshell Ventures Ltd. (Northern Miner, June 21, 1984) might provide further assessment of the PGE content in the Falcon Lake stock. Current work by the Geological Survey of Canada is providing geologic insights on what their mafic intrusive specialists have identified to be another example of layered mafic intrusives with PGE potential.

Wiley Lake, Saskatchewan

The Peter Lake Domain in northern Saskatchewan contains a gneissic, quartz-poor intrusive complex in gneissic metasedimentary host rocks. A reconnaissance PGE program in 1985 managed by Lacana Mining Corp. (joint venture partners International Platinum Corporation, Nanisivik Mines Ltd., Oakwood Petroleum Ltd. and Saskatchewan Mining Development Corporation) has discovered at least three showings and areas of platinum enrichment (Bullock, 1986; Silver Lake Annual Report, 1985). The best showing contains up to 0.16 oz/ton Pt/Pd, and a 5 m channel sample returned 0.07 oz/ton Pt/Pd.

The 1986 program will explore priority target areas, and judging by the success of the program in 1985, further encouragement is anticipated.

Rottenstone, Saskatchewan

The Rottenstone Domain is parallel and immediately southeast of the Peter Lake Domain in northern Saskatchewan, and PGE exploration activity is inspired by high PGE content in the Rottenstone Mine, a former Cu-Ni-PGE producer. The Rottenstone Mine is located about 140 km north-northeast of La Ronge, and is associated with ultramafic lenses which were intruded into lower Proterozoic sedimentary and volcanic rocks. Ultramafic lenses are small, generally up to 55 m x 40 m x 10 m. Cu-Ni ores were characteristically high in zinc, chrome, platinum and palladium. A 5,000 ton sample sent to the mill contained 4.79 g/t Pt and 3.9 g/t Pd. Graphite commonly occurs with the mineralization.

The Tremblay-Olson property, presently undergoing exploration by American Platinum Inc., is located about 2.5 km southwest of the Rottenstone Mine and is thought to be similar to the Rottenstone Mine setting (American Platinum Inc., 1986). Mineralization is also similar but the highest PGE value is reported to be 1,240 ppb Pt.

Tulameen, British Columbia

Platinum was produced from gold placer operations on the Similkameen and Tulameen Rivers near Princeton, B.C., and during the period 1885-1919, was the most productive source of platinum in North America (B. Fagan, 1986).

D.K. Platinum holds a large property in the Tulameen area with Pt mineralization in bedrock, and a large tonnage deposit is considered to be a possibility (Northern Miner, August 22, 1985). A bedrock sampling program in 1963 gave maximum values ranging from 0.205 to 6.68 g/t Pt and another sampling program in 1980-81 gave maximum values ranging from 0.02 to 2.20 g/t Pt.

Muskox, Northwest Territories

The Muskox Intrusion is a funnel shaped, cyclically layered, mafic/ultramafic body, geologically similar in many respects to the Bushveld and Stillwater Complexes. The Muskox intrusion is located about 500 km north of Yellowknife Northwest Territories, in the Coppermine River area, and is about 1.2 billion years old.

Chromitite layers and Cu-Ni sulphides containing PGE values up to 1300 ppb (0.04 oz/ton) are known to occur in the Muskox Intrusion (Bullock, 1986; Silver Lake Annual Report, 1985). No PGE reefs have been located, but properties held by International Platinum Corporation (formerly Silver Lake Resources) and Equinox will likely emphasize the search for Merensky Reef-type, UG2-type, and Platreef-type deposits.

Salt Chuck, Alaska

The Salt Chuck Prospect is a property being explored jointly by American Platinum Inc. and Orbex Industries Inc. (Northern Miner, August 4, 1986). The claims are located on Prince of Wales Island, Alaska, in a zoned mafic intrusive complex measuring about 8 km x 1.5 km, comprising pyroxenite, gabbro and diorite which have intruded dominantly metasedimentary rocks.

The Goodro Mine, a former producer, is the focus of interest on the property. About 325,000 tons of ore were mined, producing 3,100 tons Cu, 4,000-5,000 oz Pt, 20,500 oz Pd, 10,700 oz Au, and 55,000 oz Ag. The Goodro Mine has been renamed the Salt Chuck Prospect and has reserves quoted to be 285,000 tons grading 0.6% Cu, 0.076 oz/ton PGE, 0.04 oz/ton Au, 0.17 oz/ton Ag to a depth of 300 feet. A recent geochemical survey returned maximum values of 977 ppb Au, 4,600 ppb Pd and 171 ppb Pt.

La Perouse, Alaska

The La Perouse Layered Gabbro hosts a 100 million ton deposit containing 0.5% Ni and 0.3% Cu with sporadic Pt values to 0.067 oz/ton and Pd values to 0.059 oz/ton. This situation has prompted International Platinum Corporation (formerly Silver Lake Resources) to stake ground on the similar Axelgold Layered Intrusion, located about 180 km north-northeast of Smithers, British Columbia (Bullock, 1986).

CONCLUSIONS

1. About 98% of the world's PGE production comes from the Merensky Reef and UG2 layers of the Bushveld Complex, South Africa and from the Noril'sk region deposits, U.S.S.R. Minor PGE production comes from Sudbury, Ontario as a by-product of the Ni-Cu operations of Inco and Falconbridge.

2. At present, there is no primary PGE refining facility in either Ontario or the rest of North America.

3. Ontario PGE properties as well as other potential North American producers fit into a widely-accepted, global classification of PGE deposits, although the Marathon deposit might require a new class, Alkaline-type.

4. Aside from the Sudbury area most of the PGE prospects and occurrences in Ontario are in the Thunder Bay area. These include the Lac des Iles, Marathon and Crystal Lake deposits.

5. The most advanced North American PGE deposit, the J-M Reef at Stillwater, Montana, will go into production in 1987 at a planned rate of 500 tons per day to produce 25,000 oz Pt and 75,000 oz Pd per year. Planned future increases in production will ultimately result in output of 50,000 oz Pt and 150,000 oz Pd per year. The deposit is held jointly by Chevron Corp. (the operator), Manville Products Co. and Lac Minerals Ltd.

6. After Stillwater, the next most advanced PGE deposits in North America are Lac des Iles, Marathon and Crystal Lake, all located in northern Ontario. The first two deposits are mineable by open pit methods, and are considered to have good potential for production, particularly at higher platinum and palladium prices.

7. The Lac des Iles deposit, 80 km north of Thunder Bay, has estimated open pit probable reserves of 6.49 million tons averaging about 0.16 oz/ton Pd, 0.018 oz/ton Pt, 0.1% Cu and 0.1% Ni. The property is held under option by Madeleine Mines Ltd. At current metal prices and operating costs, viability would be marginal, unless substantially more tonnage is outlined that would sustain a higher rate of production. More exploration work and pre-feasibility studies are required. The property is accessible by road, but the nearest hydro electric power is about 50 km away.

8. The Marathon deposit of Fleck Resources Inc. is located 10 km from Marathon and local infrastructure is good, except for part of the access road. Estimated reserves are reported to be 46.9 million tons averaging about 0.46% Cu, 0.012 oz/ton Pt and 0.044 oz/ton Pd, plus Ni, Ag, Au and Rh values. A recent pre-feasibility review for Fleck Resources suggests that a 12,500 tpd open pit mining and milling operation would be profitable, and a feasibility study has been commissioned.

9. The Crystal Lake deposit of Great Lakes Nickel has estimated reserves of 45.6 million tons averaging 0.344% Cu, 0.183% Ni, and approximately 0.006 oz/ton Pt and 0.02 oz/ton Pd. Feasibility studies in the 1970's with respect to potential Cu-Ni production were optimistic until rising costs and interest rates caused the project to be put on standby, where it remains in 1986. At present Cu-Ni prices, the outlook for the property remains pessimistic; however, recent interest in PGE prompted Fleck Resources Inc. to option the property. The occurrence of PGE values separate from the known deposit indicates some exploration potential. Road access to the Crystal Lake property, located 50 km south of Thunder Bay, is good, but availability of electric power is uncertain.

10. Exploration potential exists in Ontario and elsewhere in North America for PGE deposits of several types, although the information base for most properties is scanty. The Thunder Bay Area in particular seems to represent a distinct PGE geological province. The Ontario Geological Survey is in the process of increasing the data base and identifying areas of potential exploration interest. In addition to the three Ontario deposits mentioned, other good prospects in and near Ontario are:

Name	Owner	Type
Big Trout Lake Ont.	International Platinum Corp.	Merensky-type or Pechanga-type
Lac Sheen, Que.	International Platinum Corp.	Pechanga-type
Fox River, Man.	BP-Selco and International Platinum Corp.	Merensky-type or Ungava sub-type

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